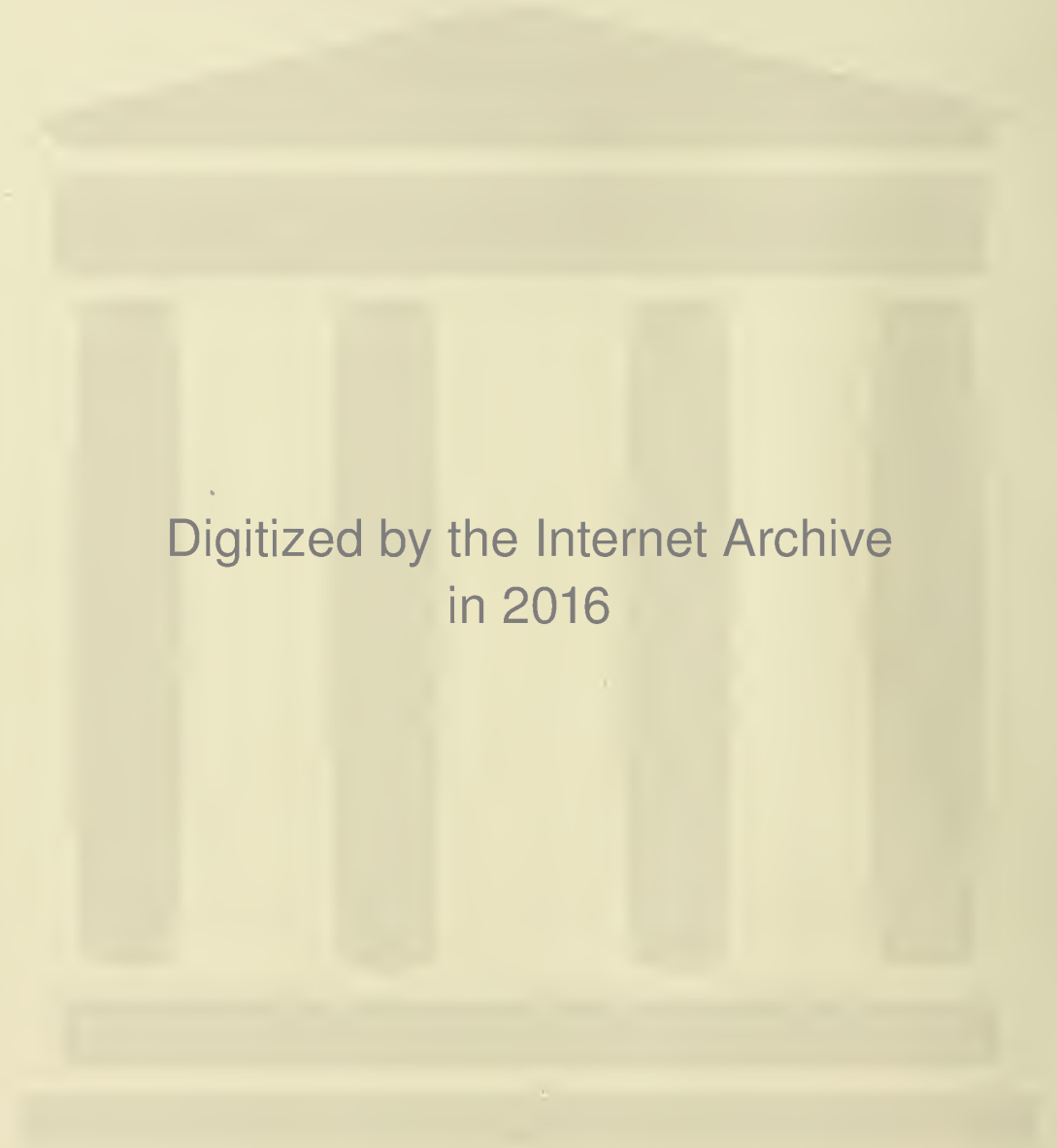
Ball and Moore

Influence of Scale on the Economic Performance Of a Locomotive Boiler

Mechanical Engineering

B. S.

1907



INFLUENCE OF SCALE ON THE ECONOMIC PERFORMANCE OF A LOCOMOTIVE BOILER

BY

John Dudley Ball
Samuel Burns Moore

THESIS FOR THE DEGREE OF BACHELOR OF SCIENCE
IN MECHANICAL ENGINEERING

IN THE
COLLEGE OF ENGINEERING
OF THE
UNIVERSITY OF ILLINOIS
PRESENTED JUNE, 1907

UNIVERSITY OF ILLINOIS

June 1, 1907

THIS IS TO CERTIFY THAT THE THESIS PREPARED UNDER MY SUPERVISION BY

JOHN DUDLEY BALL and SAMUEL BURNS MOORE

ENTITLED INFLUENCE OF SCALE ON THE ECONOMIC PERFORMANCE OF A LOCOMOTIVE BOILER

IS APPROVED BY ME AS FULFILLING THIS PART OF THE REQUIREMENTS FOR THE DEGREE

OF Bachelor of Science in Mechanical Engineering

L. P. Breckenridge

HEAD OF DEPARTMENT OF Mechanical Engineering

INFLUENCE OF SCALE

UPON

THE ECONOMIC PERFORMANCE

OF A

LOCOMOTIVE BOILER

BY

JOHN DUDLEY BALL

AND

SAMUEL BURNS MOORE

THESIS

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IN

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SYNOPSIS AND INDEX

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PART II

Tests of Clean Boiler - Series #2

APPENDIX B - FOR SERIES #2

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PRELIMINARY

The object of the tests here described was to determine the effect of scale upon the evaporative performance of a locomotive boiler.

Previous tests to determine effect of scale on transmission of heat through tubes have been made as thesis tests by-

F. H. Armstrong and J. N. Herwig	-	1899
F. L. McCune	-	1901
W. A. Miskimen and C. N. Stone	-	1904
H. F. Godeke and A. A. Hale	-	1905
A. E. Boner (for degree of M.E.)	-	1906.

The results of the first four of these thesis are summarized in Bulletin No. 11 of the Engineering Experiment Station, the conclusions of which are quoted below:

1. "Considering scale of ordinary thickness--say of thickness varying up to 1/8 inch--the loss in heat transmission due to scale may vary in individual cases from insignificant amounts to as much as 10 or 12 per cent."

2. "That the loss increases somewhat with the thickness of the scale."

3. "That the mechanical structure of the scale is of as much or more importance than the thickness in producing this loss."

4. "That the chemical composition, except in so far as it affects the structure of the scale, has no direct influence on its heat transmitting qualities."

P A R T I

Two series of tests were conducted at the round house of the C.C.C. & St.L. Railroad at Urbana, Illinois. Three tests were made upon the engine before the removal of the scale and three after. All other conditions being uniform during all trials.

The purpose of each test was to obtain the evaporation per pound of combustible actually comsumed. (See note in appendix). The final result desired was a means of comparison of the results of the two series on this basis.

MANNER OF CONDUCTING TRIALS.

Both series of tests were conducted according to American Society of Mechanical Engineers Boiler Testing Code of 1899. In each test the same methods were observed, the same grade of coal used, and the same fireman employed. EXCEPT IN TEST 6 The flues and front end were cleaned OR CLEAN before each series and all boiler conditions were the same except in regard to the scale which was removed before the second series. SEE ALSO PART II.

DATA.

The engine tested was No. 6541 belonging to the C.C.C. & ST.L.R.R. Its main dimensions are as follows:

1. Class	G .67
2. Total Weight (lbs)	185,800.
3. Weight on Drivers (lbs)	170,000
4. Weight on Truck (lbs)	15,800
5. Diameter of Cylinders (inches)	22
6. Stroke of Cylinders (inches)	30

7. Diameter of Drivers (inside tires) (inches)- 50.

8. Diameter of Boiler (outside diameter of shell) (inches) - 72

9. Number of Tubes 370

10. Outside Diameter of Tubes (inches) 2

11. Length of Tubes (inches) 164

12. Length of Fire-box (inches) 120

13. Width of Fire-box (inches) 41 1/8

14. Depth of Fire-box (inches) (Front End) 71 15/16

15. Depth of Fire box (inches) (Rear End) 75 15/16

16. Length of Grate (inches) 36 1/2

17. Width of Grates (inches) 13

18. Diameter of Dry Pipe (inches) 6 1/2

19. Diameter of Steam Dome (inches) 30

20. Height of Steam Dome (inches) 20

21. Kind of Grate Bars Rocker

22. Kind of Draft Forced

23. Type of Ejector "Monitor"

24. Service -- Freight Service on St. Louis Division.

The data observed during tests were as follows:

1. Weight of fuel fired (Wood and Coal)
2. Time of Cleaning Fires
3. Condition of Fire
4. Size and Condition of Coal.
5. Weight of Ash.
6. Weight of Water Fed to Feed Tank.
7. Height of Water in Feed Tank.
8. Height of Water in Gage Glass.

9. Steam Pressure in Boiler.
10. Pressure on Manometer (Calorimeter)
11. Pressure on Barometer.
12. Temperature of Feed Water.
13. Temperature of External Air.
14. Temperature of Round House.
15. Temperature of Flue Gases.
16. Analysis of Flue Gases.
17. Weight of Ash used to Deaden Fire at Close of Test.
18. Weight of Partially Burned Coal and Ash on Grate at Close of Test.
19. Moisture in Coal Sample.
20. Moisture in Ash Sample.
21. Moisture Partially Burned Coal Sample.
22. Condition of Weather.
23. Leakage from Boiler.

FEED WATER SHEET
FOR
BOILER TRIAL NO 1.

BY J.D. BALL — PRESENTED FOR UNDERGRADUATE.
S.B. MOORE — THESIS — JUNE 1 1907

NO. OF READ.	TIME OF READ.	WT. OF WATER	NO. OF READ.	TIME OF READ.	WT. OF WATER	NO. OF READ.	TIME OF READ.	WT. OF WATER
		LBS.			LBS.			LBS.
1	9:44	610.3	30	11:53	608.0	59	2:24	620.5
2	9:44	609.0	31	11:55	605.5	60	2:27	612.0
3	9:50	619.5	32	12:01	601.5	61	2:41	604.0
4	9:53	605.0	33	12:07	604.0	62	2:43	615.0
5	10:00	605.0	34	12:11	615.0	63	2:45	607.5
6	10:06	615.0	35	12:20	605.0	64	2:47	605.0
7	10:13	609.0	36	12:27	611.0	65	2:52	614.0
8	10:16	612.0	37	12:30	621.0	66	3:06	606.0
9	10:27	606.0	38	12:33	613.5	67	3:12	603.5
10	10:31	608.5	39	12:38	614.5	68	3:20	614.5
11	10:34	614.5	40	12:55	604.5	67	3:19	605.5
12	10:35	615.0	41	1:00	621.0	70	3:23	607.5
13	10:42	609.0	42	1:05	615.0	71	3:25	608.0
14	10:47	615.5	43	1:08	602.5	72	3:28	610.0
15	10:53	607.0	44	1:11	611.0	73	3:30	609.0
16	10:56	614.0	45	1:18	605.5	74	3:34	609.0
17	10:57	615.5	46	1:23	618.0	75	3:36	607.0
18	11:07	615.5	47	1:25	609.5	76	3:50	605.0
19	11:14	604.0	48	1:29	606.0	77	3:53	615.0
20	11:19	611.5	49	1:31	604.0	78	3:54	621.0
21	11:23	615.0	50	1:42	613.0	79	4:01	610.0
22	11:27	602.0	51	1:48	616.0	80	4:10	616.5
23	11:30	611.0	52	1:55	611.0	81	4:13	616.0
24	11:32	616.2	53	1:58	607.5	82	4:16	621.3
25	11:35	609.5	54	2:00	605.0	83	4:23	613.0
26	11:38	606.0	55	2:04	605.0	84	4:25	621.0
27	11:42	621.0	56	2:12	610.5	85	4:27	614.0
28	11:43	607.5	57	2:18	606.0	86	4:35	615.5
29	11:46	604.0	58	2:20	608.0	TOTAL		52517.3

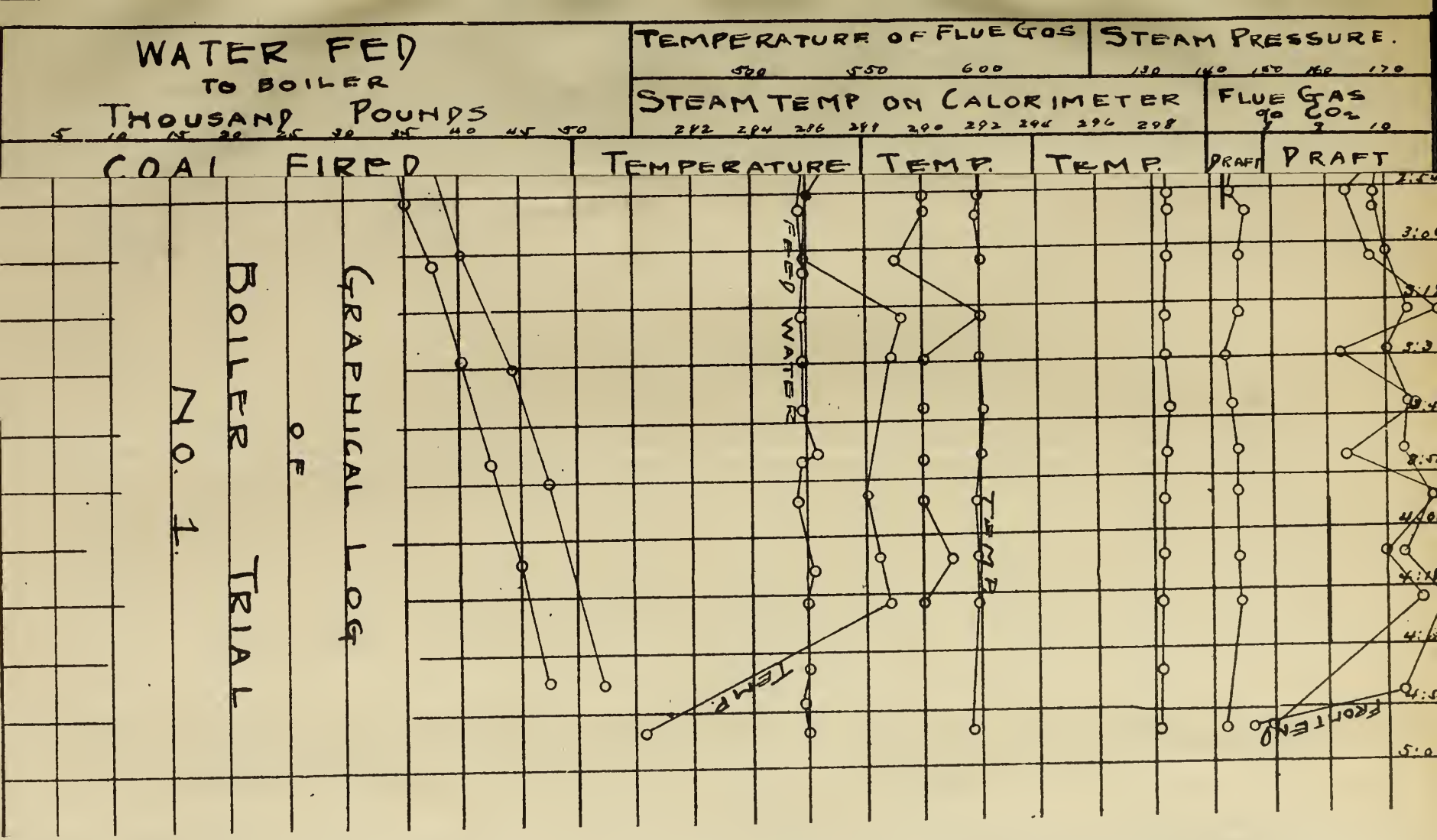
27	2:20		39.0	40.0	52.0	535	168		6.2	.050	1.200	291	.08
28	2:28	500	38.0	39.8	52.0	540	158	20.7	5.8	.037	1.200	290	.08
29	2:40		38.0	39.5	52.0	545	176		6.6	.047	1.000	290	.08
30	2:55	500	39.0	39.8	52.0	520	163	21.3	4.8	.030	.900	290	.08
31	3:00		38.0	39.5	52.0		168		3.4	.055		290	.08
32	3:08	500	39.0	40.0	52.2	520	167	21.4	3.0	.045	1.000	289	.08

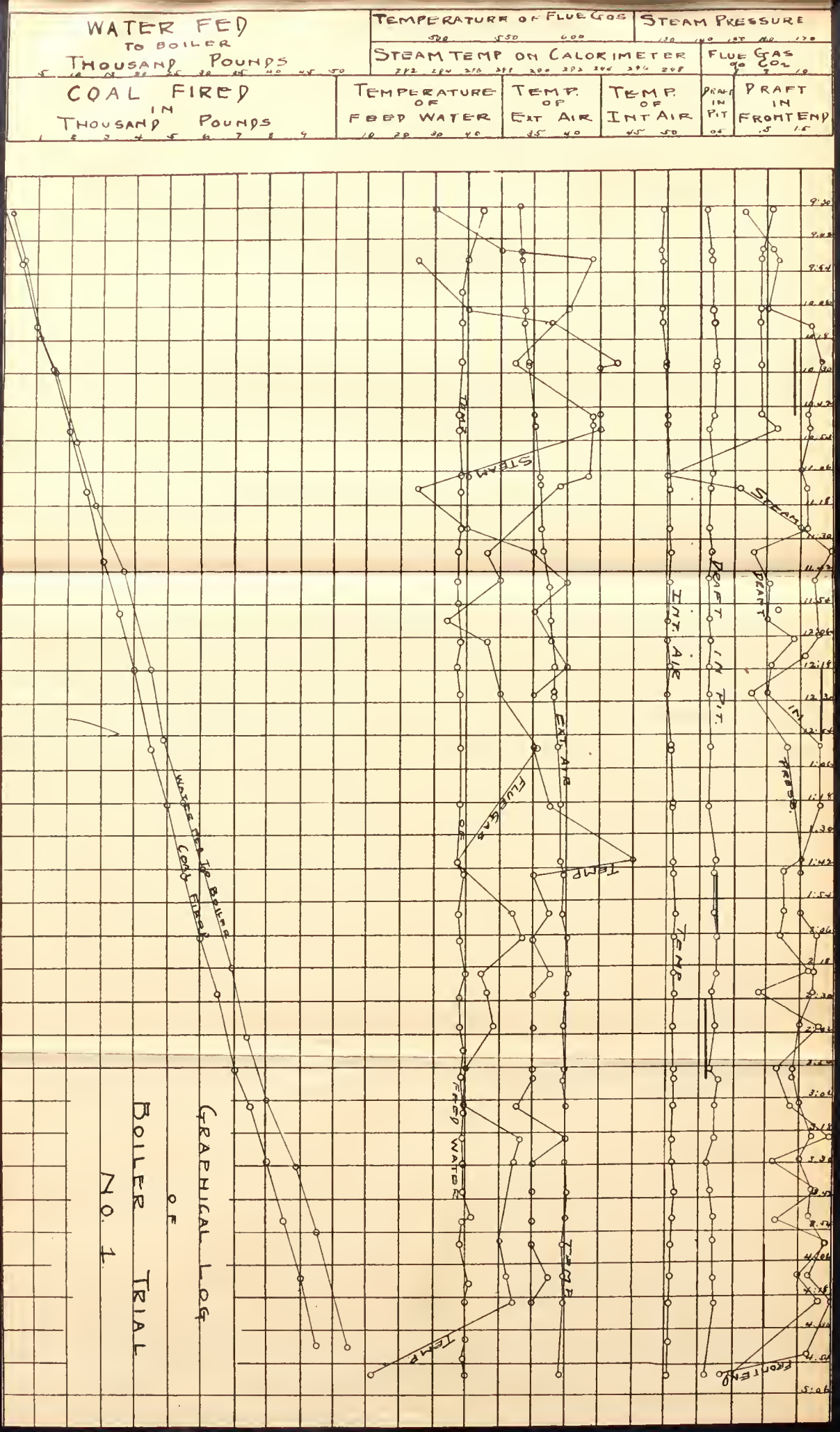
LOG SHEET
FOR
BOILER TRIAL No 1.

BY J D BALL
S.B. MOORE

PRESENTED FOR UNDERGRADUATE THESIS JUNE 1 1907

No of Reading	Time of Reading	Weight of Coal Fired	Temperatures-F°				Steam Pressure Lbs sq in	Ht of Water in Tank Inches	Ht of Water in Gage Glass Inches	Draft		Calorimeter	
			Feed Water	Ext Air	Int. Air	Flue Gas				In Pit Inches	Front End Inches	Steam Temp F°	Manometer Inches
1	9:44	133# Wood	44.0	32.6	490	500	162	4.7	6.2	.013	.150		
2	10:00		40.0	33.0	480	550	158		6.4	.030	.600		
3	10 03	500#	40.0	33.0	48.5	620	158	19.0	6.5	.030	.650	283	0
4	10 20		38.0	33.5	48.3	600	158		6.6	.034	.600	286	-.05
5	10.26	500	38.0	33.5	48.3		158	16.25	6.7	.040	1.150	291	.05
6	10:40		38.0	34.2	49.0	536	178		5.4	.045	1.300	295	.09
7	10:41	500	37.5	34.2	49.0	556	158	16.3	6.0	.045	1.300	294	.09
8	11:00		37.0	35.0	50.0	620	158		6.0	.040	1.100	294	.05
9	11.04	500	37.0	35.0	50.0	620	163	20.5	4.0	.025	1.150	294	.05
10	11.20		38.0	35.8	50.0	615	129		1.3	.035	1.000	286	.08
11	11:26	500	38.0	36.0	50.8	590	152	19.4	1.5	.030	1.000	283	.09
12	11:40		38.0	36.0	50.5		170		6.2	.025		286	.08
13	11:47	500	37.0	36.5	51.0	540	179	18.75	7.4	.033	.350	290	.08
14	12:00		37.0	37.5	50.5	550	174		7.6	.023	.550	292	.08
15	12:09	500	37.0	37.5	50.0	535	163	19.2	7.0	.025	.500	290	.08
16	12:20		39.0	37.5	50.0	540	175		6.3	.030	900	291	.08
17	12.30	500	37.0	38.0	50.8	535	169	17.3	7.5	.025	.550	292	.10
18	12:40		38.0	38.0	50.0	550	156		5.9	.025	.500	290	.08
19	12:58	500	38.0	38.5	51.0	565	169	22.0	3.6	.030	1.300	290	.09
20	1:00		38.0	38.5	51.0	565	166		4.1	.030	1.300	290	.08
21	1:19	500	38.0	39.0	51.5		168	19.4	5.2	.025	1.300	291	.09
22	1:20		38.0	39.0	51.5		168		5.2	.025	1.300	291	.08
23	1:40		37.5	39.0	52.0	530	170		5.1	.045	1.100	296	.08
24	1:44	500	39.0	39.5	52.0		165	21.4	4.9	.040	1.000	290	-.08
25	2:00		37.5	39.3	52.8	560	165		5.3	.045	1.000	291	.08
26	2:07	500	38.0	40.0	52.0	565	164	20.4	5.1	.050	1.250	290	.08
27	2.20		39.0	40.0	52.0	535	168		6.2	.060	1.200	291	.08
28	2:29	500	38.0	39.9	52.0	540	158	20.7	5.8	.037	1.200	290	.08
29	2:40		38.0	39.5	52.0	545	176		6.6	.047	1.000	290	.08
30	2:55	500	39.0	39.8	52.0	520	163	21.3	4.8	.030	.900	290	.08
31	3:00		38.0	39.5	52.0		168		3.4	.055		290	.08
32	3:08	500	39.0	40.0	52.2	520	167	21.4	3.0	.045	1.000	289	.08
33	3.20		39.0	39.8	52.0	565	179		4.1	.045	1.200	292	.08
34	3:29	500	39.0	39.8	52.0	560	162	15.9	6.7	.020	1.100	290	.08
35	3:40		39.0	40.0	52.0		175		7.1	.035	1.200	290	.08
36	3.51	500	39.0	39.8	52.5	530	163	12.9	6.8	.042	1.250	290	.08
37	4:00		38.0	39.5	51.5	550	178		5.0	.040	1.250	290	.08
38	4:10	500	41.0	39.5	51.2	555	173	13.5	5.3	.045	1.000	291	.08
39	4:20		40.0	39.5	51.0	560	181		4.5	.045	1.200	290	.08
40	4:35	500	40.0				173	17.3	5.4				
41	4:46		39.0	39.0	50.5	450	147	6.0	6.2	.020	.000		
42													
TOTAL		9500	1656.5	1505.1	2032.4	18292	6783.0			1.349	34.4	10739	-2.79
AVER.			41.4	36.5	50.85	554	165.5			.035	.93	290	-.078


WATER FED
TO BOILER
THOUSAND POUNDS
5 10 15 20 25 30 35 40 45 50
TEMPERATURE OF FLUE GOS
500 550 600
STEAM PRESSURE.
130 140 150 160 170
STEAM TEMP ON CALORIMETER
282 284 286 288 290 292 294 296 298
FLUE GAS
% CO2
DRAFT
COAL FIRED
TEMPERATURE
TEMP.
TEMP.
DRAFT
GRAPHICAL LOG
OF
BOILER TRIAL
NO. 1.
FEED WATER
TEMP
TEMP
FROM TEMP


WATER FED TO BOILER IN THOUSAND POUNDS
5 10 15 20 25 30 35 40 45 50
COAL FIRED IN THOUSAND POUNDS
1 2 3 4 5 6 7 8 9
TEMPERATURE OF FLUE GOS
500 550 600
STEAM PRESSURE
130 140 150 160 170
STEAM TEMP ON CALORIMETER
292 294 296 298 300 302 304 306 308
FLUE GAS CO2
0 5 10
TEMPERATURE OF FEED WATER
10 20 30 40
TEMP. OF EXT AIR
35 40
TEMP. OF INT AIR
45 50
DRAFT IN PIT
05
DRAFT IN FRONT END
.5 1.5
STEAM TEMP
INT AIR TEMP
DRAFT IN PIT
STEAM PRESS
FRONT END
EXT AIR TEMP
FLUE GAS TEMP
FEED WATER TEMP
WATER FED TO BOILER
COAL FIRED
GRAPHICAL LOG OF BOILER TRIAL NO. 1

FEED WATER SHEET
FOR
BOILER TRIAL NO. 2.

BY J.D. BALL.
S B MOORE.

PRESENTED FOR UNDER GRADUATE THESIS JUNE. 1. 1907.

NO. OF READ	TIME OF READ A.M.	WT. OF WATER Lbs	NO. OF READ	TIME OF READ	WT. OF WATER Lbs.	NO. OF READ	TIME OF READ	WT. OF WATER Lbs
1	8:24	615.5	37	10:46	622.0	73	1:10	616.0
2	8:24	616.0	38	10:48	610.0	74	1:15	622.0
3	8:24	615.0	39	10:54	612.0	75	1:16	616.0
4	8:33	615.7	40	10:56	616.0	76	1:23	621.0
5	8:35	615.0	41	11:01	622.0	77	1:26	616.0
6	8:45	615.0	42	11:02	607.0	78	1:30	622.0
7	8:48	620.0	43	11:09	622.0	79	1:32	616.0
8	8:52	615.0	44	11:10	613.5	80	1:38	621.5
9	8:54	621.5	45	11:15	619.0	81	1:41	616.0
10	8:54	615.5	46	11:20	616.0	82	1:42	622.0
11	9:00	622.0	47	11:28	622.0	83	1:53	616.0
12	9:05	612.0	48	11:38	616.0	84	1:58	621.0
13	9:11	619.0	49	11:43	621.0	85	2:00	616.0
14	9:16	611.0	50	11:47	616.0	86	2:03	622.0
15	9:22	621.5	51	11:50	622.0	87	2:05	616.0
16	9:24	613.0	52	11:51	616.0	88	2:15	622.0
17	9:31	615.0	53	11:53	622.0	89	2:19	616.0
18	9:34	614.5	54	11:56	616.0	90	2:20	622.0
19	9:40	622.0	55	11:59	622.0	91	2:25	616.0
20	9:45	611.0	56	12:02	616.0	92	2:27	622.0
21	9:47	620.0	57	12:05	622.0	93	2:30	616.0
22	9:50	616.0	58	12:10	616.0	94	2:41	622.0
23	9:52	622.0	59	12:13	622.0	95	2:43	616.0
24	9:58	616.0	60	12:16	616.0	96	2:44	622.0
25	10:00	622.0	61	12:27	622.0	97	2:46	616.0
26	10:04	610.0	62	12:27	616.0	98	2:48	622.0
27	10:05	615.5	63	12:30	622.0	99	2:50	616.0
28	10:07	616.0	64	12:33	616.0	100	2:53	622.0
29	10:09	616.5	65	12:36	615.0	101	3:00	616.0
30	10:12	616.0	66	12:38	616.0	102	3:02	622.0
31	10:14	619.0	67	12:40	622.0	103	3:06	616.0
32	10:15	610.0	68	12:43	616.0	104	3:09	622.0
33	10:20	622.0	69	12:45	622.0	105	3:14	616.0
34	10:26	616.0	70	12:54	622.0			
35	10:34	622.0	71	1:00	616.0			
36	10:38	616.0	72	1:02	622.0	TOTAL		64859.2

26	12:40		40.0	44.0	51.5	595	190		6.3	.055	1.00	294	.16
27	1:00		39.0	44.0	52.8	548	185		4.7	.050	1.40	296	.14
28	1:02	500	39.0	44.0	52.8	545	165	20.8	4.0	.040	1.40	292.5	.12
29	1:18	500	39.5	44.5	54.0	560	155	18.9	3.1	.035	1.40	294	.13
30	1:20		39.0	44.5	54.0	555	162		3.3	.035	.90	294	.12
31	1:38	500		45.3	53.2	555	172	14.3	2.4	.035	.90	294	.13

LOG SHEET
FOR
BOILER TRIAL NO 2

By JD Ball
SB Moore

Presented for Undergraduate Thesis June. 1.1907.

No of Reading	Time of Reading	Weight of Coal Fired Lbs	Temperatures. Feed Water	Ext. Air	Int Air	Flue Gas	Steam Pressure Lbs per Sq In	Ht. of Water in Tank Inches	Ht of Water in Gage Glass Inches	Draft. In Pit. Inches	Draft. Front End Inches	Calorimeter. Steam Temp. F°	Calorimeter. Manometer Inches
1	A.M. 8:24	Wood 170#	41.0	31.0	47.5	445	180	5.0	4.6	.030	.30		
2	8:40		41.0	32.0	48.0	520	176		4.7	.030	.40	288	.08
3	8:43	500	41.0	32.0	48.0	525	165	15.0	4.6	.030	.70	289	.12
4	9:00		39.0	38.0	47.0	570	165		6.7	.050	.85	292	.12
5	9:02	500	39.0	33.2	47.5	575	178	22.2	6.6	.040	1.00	293	.11
6	9:20		39.0	34.2	47.5	575	165		5.0	.050	1.90	294.4	.13
7	9:26	500	39.0	34.8	47.0	540	150	20.4	4.2	.030	.90	293	.13
8	9:40		39.0	35.0	47.0	580	174.5		3.5	.045	1.00	295	.13
9	9:42	500	39.0	35.3	47.0	578	173	19.6	3.3	.045	.50	296	.12
10	9:57	500	39.0	36.0	47.0	600	180	18.8	3.7	.050	1.50	296	.12
11	10:00		39.0	36.0	47.0	600	176		4.3	.050	1.20	295	.12
12	10:19	500	39.0	37.5	48.0	585	168 169	19.8	2.8	.045	1.30	296	.13
13	10:35	500	390	38.3	48.0	602	173	21.8	3.2	.040	1.30	296	.13
14	10:40		39.0	38.5	48.5	600	174		3.8	.053	1.50	296	.14
15	10:52	500	39.0	39.8	49.0	570	170	21.4	2.1	.020	1.60	299	.14
16	11:00		39.0	40.0	50.0	570	167		2.3	.050	1.50	295.5	.14
17	11:05	500	39.0	40.5	50.0	570	157	20.7	2.4	.035	.90	299	.15
18	11:20		39.0	40.5	50.0	550	144		1.5	.060	1.30	292	.14
19	11:31	500	39.0	41.5	50.5	530	154	21.0	4.6	.060	1.70	278	.00
20	11:40		39.0	42.2	50.0	555	167		3.8	.040	1.50	290	.14
21	11:44	500	39.0	42.2	50.0	570	178	14.0	5.0	.060	1.10	292	.14
22	P.M. 12:00	500	39.0	42.5	51.5	585	166	21.6	5.4	.045	2.00	296 296	.14 .14
23	12:15	500		43.0	52.0	568	168		5.1	.040	1.65	296	.14
24	12:20		39.0	43.5	51.5	573	170		5.2	.050	1.70	296	.15
25	12:34	500	39.0	43.8	52.8	595	173	19.3	6.0	.025	1.50	298	.13
26	12:40		40.0	44.0	51.5	595	190		6.3	.055	1.60	297	.15
27	1:00		39.0	44.0	52.8	548	185		4.7	.050	1.40	296	.14
28	1:02	500	39.0	44.0	52.8	545	165	20.8	4.0	.040	1.40	292.5	.12
29	1:18	500	39.5	44.5	54.0	560	155	19.9	3.1	.035	1.40	294	.13
30	1:20		39.0	44.5	54.0	555	162		3.3	.035	.90	294	.12
31	1.38	500		45.3	53.2	555	172	14.3	2.4	.035	.90	294	.13
32	1:40		39.0	45.3	53.2	550	156		2.8	.035	.90	292	.12
33	1:55	500	40.0	45.8	54.0	535	139	17.0	1.0	.020	1.50	292	.12
34	2:00		40.0	45.8	54.5	545	160		1.0	.032	1.30	290	.14
35	2:16	500	40.0	46.0	55.2	575	148	13.1	2.0	.020	1.50	289	.10
36	2:20		40.0	46.0	55.0	545	163		1.8	.050	1.60	289	.10
37	2:33	500		46.0	55.0	540	179	19.0	2.0	.020	1.70	292	.10
38	2:40		40.5	46.0	55.5	555	190		2.4	.040	1.50	294	.00
39	2:53	500	400	46.5	56.0	575	185	21.2	3.0	.030	.90	290	.14
40	3:00		40.0	46.7	56.0	548	160		3.2	.047	1.00	291.5	.14
41	3:18	500		46.5	55.5	535	164	8.1		.030	1.00	296	.14
42	3:20		40.5	46.5	55.5	535	160		5.0	.030	1.00	290	.14
43	3:26		41.0	47.0	56.0		171	5.35	4.6	.000	0.00		.00
Total		11000	1567.5	1766.7	2201.5	2359.2	7476.5			.677	51.7	12313.9	-51.5
Aver.			39.2	41.1	51.2	561.0	169.5			.0395	1.23	294.2	-.123

FEED WATER SHEET
FOR
BOILER TRIAL NO. 3.

BY J D BALL
S B MOORE

PRESENTED FOR UNDERGRADUATE THESIS
JUNE 1. 1907

NO. OF READ.	TIME OF READ	WT. OF WATER Lbs.	NO. OF READ.	TIME OF READ	WT. OF WATER Lbs.	NO. OF READ.	TIME OF READ	WT. OF WATER Lbs.
1	3:27	622	33	6:09	616	65	8:24	616
2	3:27	616	34	6:16	622	66	8:26	622
3	3:29	622	35	6:18	616	67	8:30	616
4	3:54	616	36	6:20	622	68	8:31	622
5	3:56	622.5	37	6:23	616	69	8:36	616
6	3:59	616	38	6:30	622	70	8:38	622
7	4:02	622	39	6:42	616	71	8:41	616
8	4:04	616	40	6:45	622	72	8:51	622
9	4:12	622	41	6:48	616	73	8:57	616
10	4:14	616	42	6:57	622	74	9:01	622
11	4:21	622.5	43	7:04	616	75	9:06	616
12	4:31	616	44	7:06	622	76	9:14	622
13	4:41	622	45	7:10	616	77	9:16	616
14	4:57	616	46	7:18	622	78	9:22	622
15	4:57	622	47	7:24	616	79	9:23	616
16	5:01	622	48	7:26	622	80	9:28	622
17	5:03	616	49	7:34	616	81	9:30	616
18	5:15	622	50	7:36	622	82	9:35	622
19	5:16	616	51	7:39	616	83	9:37	616
20	5:22	622	52	7:40	622	84	9:40	622
21	5:23	616	53	7:46	616	85	9:45	616
22	5:29	622	54	7:48	622	86	9:48	622
23	5:31	616	55	7:50	616	87	9:49	616
24	5:39	622	56	7:53	622	88	9:51	622
25	5:41	616	57	7:57	616	89	9:55	616
26	5:43	622	58	8:00	622	90	9:58	622
27	5:48	616	59	8:05	616	91	10:01	616
28	5:52	622	60	8:05	622	92	10:11	622
29	5:54	616	61	8:11	616	93	10:13	616
30	5:58	622	62	8:13	622	94	10:16	622
31	6:01	616	63	8:15	616	95	10:18	616
32	6:07	622	64	8:22	622	TOTAL		58809.

28	8:18	500	40.5	45.0	54.0	615		21.5		.035	1.50			
29	8:20		40.5	45.0	54.0	615	192		2.750	.035	1.50	297	.00	
30	8:37	500	40.0	45.0	54.0	610	173	18.8	3.50	.030	1.60	297	.00	
31	8:40		40.0	45.0	54.0	580	157		3.875	.040	1.20	296	.00	
32	9:00		40.0	45.8	54.5	565	148		1.500	.010	1.50	291	.00	
33	9:02	500	40.0	45.8	54.5	565		17.3		.010	1.50			
34	9:17	500	40.5	46.2	55.0	570	153	19.0	1.000	.040	1.30	291	.00	

LOG SHEET
FOR
BOILER TRIAL NO. 3

BY J.D. BALL
S.B. MOORE

PRESENTED FOR UNDERGRADUATE THESIS JUNE 1907

No of Reading	Time of Reading	Weight of Coal Fired Lbs.	Temperatures				Steam Pressure Lbs. per sq. in.	Ht. of Water in Tank Inches	Ht. of Water in Gage Glass Inches	Draft		Calorimeter	
			Feed Water °F.	Ext. Air °F.	Int. Air. °F.	Flue Gas °F.				In Pit. Inches	From End Inches	Steam Temp °F.	Manometer Inches
1	PM 3.27	1495 Wood	43.0	51.2	56.5	398	142	5.75	3.125		.20		1
2	3.40		43.0	51.2	57.0	430	133		1.875		.40		
3	3.57	500	42.5	50.2	57.0	520	146	19.5	1.50	.020	.50		
4	4.00		42.0	50.3	57.0	545	178	--	3.63	.030	.90		
5	4.09	500	42.0	50.0	57.0	540	172	20.75	5.75	.030	.80		
6	4.20		42.0	50.5	56.5	540	176		8.00	.020	.40		
7	4.40		42.0	50.0	57.0	580	156		5.26	.030	1.05	294	0.00
8	4:43	500	42.0	50.0	57.0	580	160	18.2	5.00	.030	1.05	295	0.00
9	5.00		44.0	49.8	57.5	580	177		2.89	.045	1.30	294	.00
10	5.09	500	43.0	50.0	57.3	595	170	20.8	2.125	.030	1.30	294	-.10
11	5:20		42.0	49.0	57.0	600	165		2.25	.050	1.10	294	-.10
12	5:30	500	41.5	49.0	57.0	520	141	20.	2.25	.035	1.10	290	-.10
13	5:40		41.5	49.0	57.0	600	162		2.13	.050	1.30	294	-.05
14	5.54	500	41.5	49.0	57.0	530	156	21.0	3.50	.030	1.10	290	-.00
15	6:00		41.0	48.2	57.0	565	156		4.00	.050	1.00	292	.00
16	6:16	500	41.0	48.0	56.5	570	175	18.75	3.75	.030	1.50	294	.00
17	6.20		42.0	48.0	56.5	555				.042	1.10		
18	6:40		41.0	46.2	56.0	555	165		2.875	.020	1.30	292	.00
19	6.47	500	41.5	46.2	56.0	520		14.4		.030	.90		
20	7.00		42.0	46.0	57.0	550	158		1.75	.047	1.00	290	.00
21	7:09	500	41.5	46.2	56.2	555	145	19.0	1.50	.030	1.00	288	.00
22	7.20		41.0	46.0	57.0	555	143		1.00	.035	1.30	287	.00
23	7:29	500	41.5	46.5	57.0	555	147	18.6	1.375	.025	1.65	290	.00
24	7:40		41.0	46.0	56.0	575	176		1.00	.035	1.50	293	.00
25	7:42	500	41.0	46.0	56.0	575		14.5		.035	1.50		
26	8:00		41.0	46.0	54.5	590	172		2.875	.020	1.00	295	00
27	8:03	500	40.5	46.0	54.5	590		19.7		.020	1.00		
28	8:18	500	40.5	45.0	54.0	615		21.5		.035	1.50		
29	8:20		40.5	45.0	54.0	615	192		2.750	.035	1.50	297	.00
30	8:37	500	40.0	45.0	54.0	610	173	18.8	3.50	.030	1.60	297	.00
31	8:40		40.0	45.0	54.0	580	157		3.875	.040	1.20	296	.00
32	9:00		40.0	45.8	54.5	565	148		1.500	.010	1.50	291	.00
33	9:02	500	40.0	45.8	54.5	565		17.3		.010	1.50		
34	9:17	500	40.5	46.2	55.0	570	153	19.0	1.000	.040	1.30	291	.00
35	9:20		40.5	46.2	55.0	570	153		1.000	.040	1.30	291	.00
36	9:38	500	42.0	45.5	54.0	600	159	18.7	3.125	.055	1.30	289	.00
37	9:40		41.5	45.5	54.0	600	195		3.375	.055	1.30	291	.00
38	10:00		42.0	46.5	54.0	555	162		6.125	.045	1.10	291	.00
39	10:03	500	42.0	45.5	54.0	555	162	20.7	5.75	.020	1.10	291	.00
40	10:20		42.0	46.0	54.0	572	168		5.50	.020	1.30	291	.00
41	10.22	500	42.0	46.0	54.0	572		21.4		.045	1.30		
42	10:34		42.0				152	10.75	3.125	.000		292	.00
Total		9500	1747.5	1942.5	2287	23012	5637			1.299	48.05	8459	.35
Aver.			41.5	45.05	55.8	561	160.8			.036	1.172	292	.00

The tests were started and stopped by "Standard Method" (See A. S. M. E. Code 1899, Section X). At the close all draft was shut off and the fire on the grates smothered with a weighed amount of ash. After cooling, the mixture of partially burned coal and ash was weighed and samples taken to determine moisture and chemical analysis.

Samples of coal and of ash were likewise taken for moisture determination and for analysis by method of quartering (See A. S. M. E. Code, Section XV).

In the case of partially burned coal and the ash the entire amounts were quartered. In the case of the coal a 500 pound sample was collected from a few pounds out of each lot fired.

METHODS OF OBTAINING DATA.

Item 1. Weight of fuel was observed from weight of coal fired in 500 lb. lots which ~~were~~ carefully weighed on platform scales.

Item 2. Time of cleaning fires was observed and recorded.

Item 3. Condition of fire was observed at end of firing each 500 pound lot of coal.

Item 4. Size and condition of coal was obtained from sorting a representative sample of coal.

Item 5. The weight of ash was taken every hour and at close of test.

Item 6. The weight of water was taken when fed from weighing tanks to feed tank.

Item 7. Height of water in feed tank was measured at end of firing 500 pound lots of coal.

Items 8--15. Height of water in gage glass, pressures and temperatures taken at regular 20 minute intervals and at end of firing each 500 pounds of coal.

Item 16. Flue gas samples were taken at irregular intervals and analysed by Orsat apparatus.

Item 17. Weight of ash used to deaden fire taken before close of test.

Item 18. Weight of partially burned coal and ash taken after close of test.

Item 19. - 21. Representative samples of coal, ash and partially burned coal were weighed and dried in boiler room at shops and samples reweighed after 15 hours drying. (See A. S. M. E. Code Section XV).

Item 22. The condition of weather observed during test.

Item 23. The weight of leakage from boiler was observed twice during test No. 2 and at irregular intervals during test No. 3. All leakage from boiler being collected for observed periods of time and the collected leakage weighed. (See Appendix)

The water ejected by priming the ejector was caught in a vessel and returned to the feed tank.

ARRANGEMENT AND DESCRIPTION OF APPARATUS.

The engine was placed on track No. 10 in the round house and the tender removed. The connecting rods were removed and the valves set forward and blocked in such a manner that no steam could enter the cylinders. The throttle was closed and blocked. A 40-ton car of coal was placed on an

adjoining track in the round house and a large platform built from the rear end of the engine to the edge of the coal car. This platform was on a level with the apron of the engine and upon it was placed a hopper mounted on platform scales in which 500 pound lots of coal were weighed. Coal was passed from the car to the platform and weighed as needed.

To the right of the engine was a platform upon which was placed a large feed tank, from the bottom of which a pipe line was extended to connect to both injectors, either one of which could be cut out by means of ~~closing~~ a globe valve. Two weighing tanks were mounted upon platform scales which were on a platform so built that the weighing tanks could be emptied into the feed tank as needed.

The steam was taken from the dome of the boiler and piped through a two inch pipe to the hood over the engine and exhausted to the atmosphere. The steam pressure was maintained by means of a globe valve inserted in the pipe line near the dome. During the tests the valve was opened to discharge the amount of steam necessary to drive the engine WHEN carrying an average tonnage. This was estimated on basis of the average coal consumption on road. The steam pressure was read on a Crosby test gage.

About eighteen inches from the dome the two inch steam pipe was bushed up to three inches and a short three inch pipe inserted in the pipe line. Into this was placed a sampling pipe leading to a Carpenter throttling calorimeter. On this was read the pressure and temperature of the throttled

steam. For a description of this calorimeter see Carpenter's Experimental Engineering Page 421 (et S.E.O. ~~sic~~) Edition 1906.

Barometer pressures were taken for dates of the tests from the records of weather bureau at the University of Illinois.

The feed water temperature was taken in feed tank.

The temperature of round house was taken from a thermometer located at one end of the coal car.

The temperature of external air was taken from a thermometer on the exterior side of the north wall of the round house.

Temperature of flue gas was taken by EIMER AND AMEND mercury pyrometer inserted into the front end of engine six inches in front of the petticoat pipe and near top of the shell.

The flue gas samples were taken through a hand hole on the right side of the boiler about two feet from the front end. The samples were obtained by means of a 1/4 inch sampling pipe three feet long which was gradually moved backward and forward through the opening, by which means an average sample was obtained. This pipe was connected by a rubber hose to a small aspirator which pumped gas into a bottle by means of displacement of water. The gas was then transferred from the bottle to an orsat apparatus by the method of water displacement. (See Figure 1 Page 15a). The analysis was made according to the method described in Carpenter's Experimental Engineering, Page 474.

The weights of ash, partially burned coal, and coal samples were found on platform scales. The moisture samples,

FIGURE 1

FRONT END ARRANGEMENTS — — ENGINE 6541

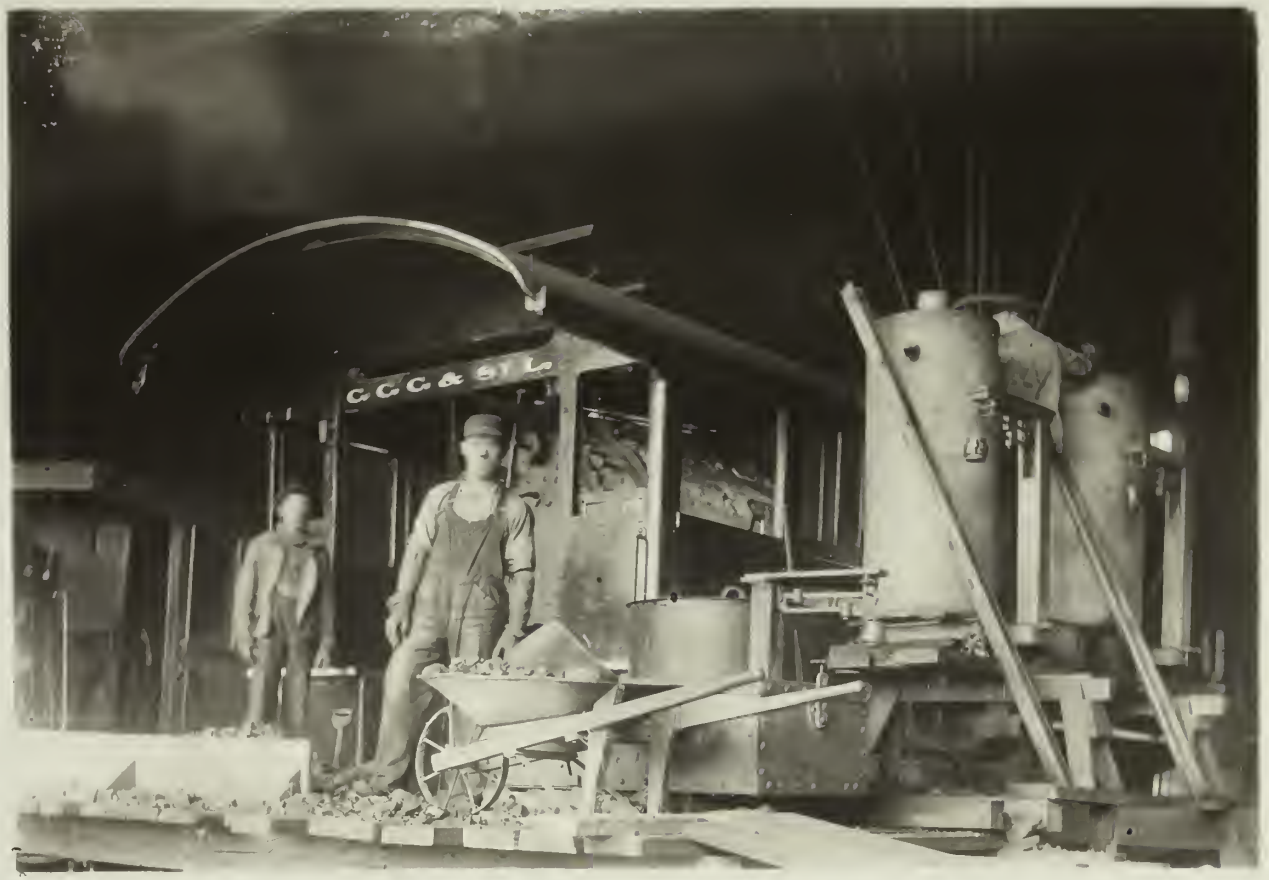


FIGURE 2

REAR END ARRANGEMENTS — ENGINE 6541

leakage, etc., were weighed on a small pair of "Buffalo" scales. All of the instruments; (Scales, etc)., used were carefully calibrated and found to be accurate.

CALCULATED DATA AND RESULTS

1. Governing Proportions of Engine.

1.1	Grate surface, square feet -	34.3
1.2	Water heating surface, square feet-	2827.25

RESULTS OF BOILER TRIALS

2. Time and Duration				
2.1	Number of test -	1	2	3
2.2	Date of trial	2/25/07	2/27/07	2/28/07
2.3	Duration of trial in hours	7.03	7.03	7.117
3. Average Pressures				
3.1	Steam pressure in boiler, by gage, pounds per square inch -	165.5	169.5	160.8
3.2	Atmospheric pressure, inches of mercury -	29.57	29.46	29.34
3.3	Manometer (calorimeter), inches of mercury -	.078	.123	.000
3.4	Force of draught, in inches of water, front end	.93	1.23	1.172
3.5	Force of draught, in inches of water, in ash pit -	.035	.039	.036
4. Average Temperatures, DEGREES FAHR.				
4.1	Of external air, degrees -	38.5	41.4	45.0
4.2	Of round house, degrees -	54.8	51.2	55.8
4.3	Of steam in boiler, degrees -	373	375	371
4.4	Of steam in calorimeter, degrees-	290.0	294.2	292.0

		Test No. 1	2	3
4.5	Of feed water entering ~~boiler~~ INJECTOR degrees -	41.4	39.2	41.5
4.6	Of escaping gases, degrees -	554	561	561
5.	**Fuel**			
5.1	Moist coal consumed, pounds -	9,500	11,000	9,500
5.2	Wood consumed, pounds -	133	170	149.5
5.3	Coal equivalent of wood (item = 5.2 x .4), pounds -	53	68	60
5.4	Total coal consumed including wood equivalent, pounds -	9,553	11,068	9,560
5.5	Moisture in coal, per cent -	10.15	10.56	10.72
5.6	Dry coal consumed, pounds -	8,580	9,910	8,535
5.7	Total ash and refuse, pounds -	1,392	1,192	1,148
5.8	Total conbustible, pounds -	7,405	8,415	7,170
	Fuel per Hour			
5.9	Dry coal consumed per hour, lbs.	1,220	1,410	1,198
5.10	Combustible consumed per hour, pounds -	1,052	1,196	1,007
5.11	Dry coal per square foot of grate surface, per hour, lbs.-	35.58	41.08	34.95
5.12	Combustible per square foot of water heating surface, per hour pounds -	.372	.423	.356
	Proximate Analysis of Coal			
5.13	Fixed Carbon, per cent -	39.93	39.24	38.75
5.14	Volatile matter, per cent -	37.60	36.74	36.28
5.15	Moisture, per cent -	10.15	10.56	10.72

		Test. No. 1	2	3
5.16	Ash, per cent -	12.32	13.46	14.25
5.17	Combustible (Item ~~5.11~~ + ~~5.12~~ 5.13 + 5.14) -	77.53	75.98	75.03
	(For Ultimate Analysis see Appendix)			
	Caloric Value of Fuel.			
5.18	By oxygen calorimeter per pound coal B. T. U.	11,160	10,830	10,793
5.19	By oxygen calorimeter per pound combustible B. T. U.	14,400	14,250	14,750
5.20	By analysis per pound coal, B. T. U. -	11,203	10,958	10,881
5.21	By analysis per pound combustible, B. T. U. -	14,455	14,440	14,510
6.	Water			
6.1	Total water fed to feed tank, lbs	52,517	64,859	58,809
6.2	Correction for level in tank, "	-175	-100	-75
6.3	Total water fed to boiler, lbs.	52,342	64,759	58,134
6.4	Leakage from boiler, lbs.	0	903	2,947
6.5	Water fed to boiler corrected for leakage, lbs. -	52,342	63,856	55,187
6.6	Equivalent water fed to boiler from and at 212 degrees, lbs. -	63,800	78,500	67,750
6.7	Moisture in steam, per cent -	1.06	.921	.96
6.8	Quality of steam (dry steam = unity). -	.989	.9907	.9903
6.9	Water actually evaporated corrected for quality of steam, lbs-	51,750	63,250	54,640
6.10	Factor of Evaporation -	1.219	1.229	1.2275
6.11	Equivalent water evaporated into dry steam from and at 212 degrees			

	Test No. 1	2	3
(Item 6.9 x 6.10), pounds -	63,120	77,750	67,080
6.12 Water evaporated per hour corrected for quality of steam, lbs.-	7,365	8,999	7,680
6.13 Equivalent evaporation per hour from and at 212 degrees, lbs -	8,980	11,055	9,430
6.14 Equivalent evaporation per hour from and at 212 degrees per square foot of water=heating surface lbs. -	3.175	3.920	3.354
7. Horse Power			
7.1 Horse-power developed (34 1/2 lbs. of water evaporated per hour into dry steam from and at 212 degrees= one horse power), H. P. -	260	321	273
8. Efficiency			
8.2 Efficiency of boiler; heat absorbed by boiler per lb. of combustible divided by heat value of one pound of combustible, per cent	57.1	62.6	62.2
9. Evaporative Performance			
9.1 Water apparently evaporated under actual conditions per pound of coal as fired (Item 6.5 ÷ Item 5.4) lbs -	5.48	5.77	5.77
9.2 Equivalent evaporation from and at 212 degrees per pound of dry coal. (Item 6.11 ÷ Item 5.6), lbs -	7.36	7.85	7.86

9.3 Equivalent evaporation from and at 212 degrees per pound of coal as fired (Item 6.11 ÷ Item 5.4), lbs	6.61	7.02	7.02
9.4 Equivalent evaporation from and at 212 degrees per pound of combustible (Item 6.11 ÷ Item 5.8) pounds -	8.530	9.235	9.46
10. Economic result Desired in these tests			
10.1 Equivalent evaporation from and at 212 degrees per pound of net combustible actually ~~absorbed~~ consumed by boiler -	9.74	10.14	9.97

METHODS OF CALCULATION

Item 1.1- The grate surface was calculated from grate measurements.

Item 1.2 - The water heating surface was taken as the total heating surface of tubes + the area of the side sheets and the crown sheet.

Items 3 & 4 - The pressure and temperature averages are averages calculated from observed readings.

Item (5.5, 5.13---5.21) - The moisture, carbon, volatile matter and ash were given ~~from~~ by chemical analysis.

Item 6.4 - Calculated from leakage, the leakage from boiler was observed, for known periods of time. The leakage at various intervals of time was collected and weighed and rate of leakage in pounds per minute calculated for these

periods. Leakage rate between these periods was taken as the average of leakage at beginning of the period and the end. The sum of these being taken as the total leakage (See Appendix)

Item 6.6 - The equivalent water at 212 degrees was calculated from method in A. S. M. E. Code 1899.

Item 6.7 - The moisture in steam was calculated from calorimeter DATA referred to in Carpenter's Experimental Engineering

Item 6.10 - The factor of evaporation was found from the curve in the above reference and calculated by formula therein given

Item 8 - The efficiency was calculated as Item 6.11 x latent heat at 212 degrees ÷ Item 5.8 ÷ Item 5.21.

Item 9 - The evaporative performance was calculated as specified in Items.

Item 10 - The total combustible in above Items refers to combustible represented by the coal and wood. By net combustible is meant combustible in fuel minus combustible in ash and partially burned coal on grate at end of test. (See Appendix).

DATA IN REGARD TO SCALE.

In order that these tests might be compared with others an effort was made to obtain all possible imformation in regard to scale. The boiler was divided in twelve parts and at each was found average thickness, total weight of scale, and representative samples WERE TAKEN for chemical analysis and specific gravity determinations. The samples taken were

from the following locations in boiler:

Sample No. 1 - The upper 130 tubes from the boiler were taken out and calipered. Every third tube was calipered at various points along the length and the average of about 100 readings taken. From these tubes a large sample was taken and quartered for analysis.

Sample No. 2 - The same method as above used for the center 130 tubes of boiler.

Sample No. 3 - The same method as above used for the lower 110 tubes.

The tubes were then all weighed and taken in lots of 60 to a rattler for cleaning. The tubes were again weighed after cleaning and the weight of scale found being the difference of the two weights.

Sample No. 4 - was taken from the right half of boiler shell. The thickness was taken as an average of 38 readings.

Sample No. 5 - was taken from the left side of the shell, the thickness being an average of 46 readings.

Sample No. 6 - was taken by method of quartering the loose mud in the bottom of the shell. This mud was of the texture of coarse sand and contained a large per cent of moisture. A sample to determine moisture was to be taken but the mud was unfortunately ~~removed~~ DISCARDED before this was done.

Sample No. 7 - was taken from the rear flue sheet.

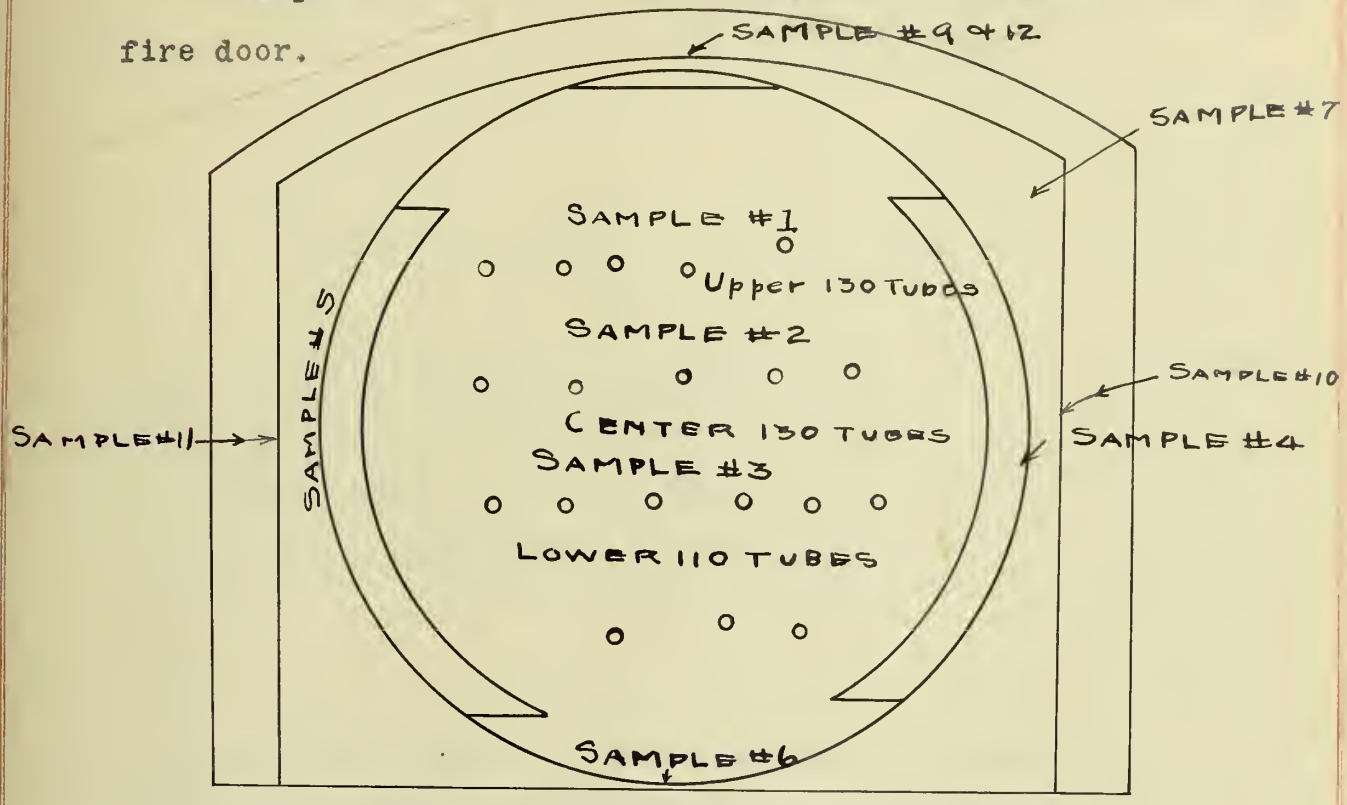
Sample No. 8 - was taken from the front flue sheet.

Sample No. 9 - was taken from the crown sheet near the rear flue sheet.

Sample No. 10 - was taken from the right side sheet.

Sample No. 11 - was taken from the left side sheet.

Sample No. 12 - was taken from the crown sheet near the fire door.



Sketch Showing Locations Referred To Above.

Analysis of these samples were made by the Department of Chemistry of the University of Illinois and are as follows: (See next page)

DATA ON SCALE

Location Number		Thickness of Scale.
1	-	5/128 "
2	-	3/64 "
3	-	3/128 "
4	-	3/16 "
5	-	11/64 "
7	-	1/16 "
8	-	5/64 "

Location Number (cont.)		Thickness of Scale (cont.)
9	-	7/64 "
10	-	3/64 "
11	-	3/64 "
12	-	7/64 "

There was no scale on bottom of shell except the loose mud.

1. Total Weight of Scale on Tubes (lbs) - 1,221.50
2. Total Weight of Scale on boiler from Crown Sheet, shell and Fire Sheets (lbs) - 713.13
3. Weight of Loose Wet Mud in Shell (lbs) - 1,229.50

Total Weight of Scale (lbs) - 3,164.13

Specific gravity of scale on tubes as calculated from outside surface of tubes, thickness and weight of scale - 2.276

Weight of Scale per cu. ft. (lbs) - - - - - - - - - 143.

ANALYSIS OF BOILER SCALE.

Sample.	Silica. SiO_2.	Iron & Aluminum Oxides. Fe_2O_3 & Al_2O_3	Calcium Sulphate. $CaSO_4$	Calcium Carbonate. $CaCO_3$	Calcium Oxide. CaO.	Magnesium Carbonate. $MgCO_3$.	Magnesium Oxide. MgO.	Moisture.	Undetermined.
1	7.66	5.62	56.54	11.28	.67		11.00	.83	6.40
2	9.26	8.32	43.27	21.42		1.09	9.70	.71	6.23
3	7.92	5.92	7.64	63.24		1.26	7.94	.79	5.29
4	18.16	12.14	6.60	21.38	9.83	.	20.36	2.51	9.02
5	15.82	7.40	7.31	22.54	8.33		24.58	2.68	11.54
6	8.06	8.00	6.46	56.23		.88	10.82	2.58	6.97
7	5.58	3.86	50.14	7.01	2.63		19.60	.64	10.54
8	15.52	5.90	22.45	23.20	11.41		13.72	1.79	6.01
9	11.04	1.00	35.50	17.54	.11		15.60	1.58	8.63
10	6.08	6.20	42.64	18.24	3.44		13.76	.90	8.74
11	9.02	6.74	30.80	17.61	4.18		20.08	.90	10.67
12	10.52	9.30	31.13	19.27	3.00		17.38	1.35	8.05

APPENDIX A - FOR SERIES I

OBSERVERS.

The general supervision of the tests herein described was in charge of J. D. Ball while the front end arrangements were in charge of S. B. Moore who also made the flue gas analysis. Other observers for first series of tests were students in Mechanical Engineering at the University of Illinois as follows:

R. E. Robinson	O. A. Cumming
G. E. Munger	G. S. Fossland.
A. S. Buyers	S. M. Berolzheimer
F. Van Inwagen	L. N. Bowman
R. K. Hursh	A. B. Cooke
John Nydigger.	

The fireman for the tests of series I was fireman Lucot employed by the C. C. C. & St. L. R. R. Co.

CALIBRATION OF INSTRUMENTS.

All instruments were calibrated and were corrected until accurate when necessary. The thermometers were calibrated in water and steam baths and compared with Standard at Mechanical Engineering Laboratory. Scales were calibrated with test weights. The test gage was calibrated with Crosby test gage. Calibration of feed tank was made using water at a temperature of 60° (See curve page 34)

C O A L.

The same coal was used for all tests, the coal left after the first series of tests being taken care of in round house until the second series was made. The determination of moisture made by drying gave the following results:

Test No.	Wt. of coal before drying lbs.	Wt. of coal after drying lbs.	per cent moisture
1	13.625	12.5	8.25
2	17.812	15.75	11.66
3	12.437	11.625	6.52

Mechanical sorting of a sample of about 500 pounds showed the following:

	1st Trial	2nd Trial
Lump (per cent) -	21.4	20.6
Small (per cent) -	27.4	26.3
Slack (per cent) -	51.2	53.1

The small being taken through two inch mesh and slack through a three-fourths inch mesh.

The ultimate analysis of the coal is as follows:

Test No.	1	2	3
Carbon (C)	61.15	59.70	59.31
AVAILABLE Hydrogen (H)	3.48	3.38	3.35
Sulphur (S)	3.73	4.42	4.27
Ash	12.32	13.46	14.25

Barometer Readings on Dates of Tests.

	7 A.M.	2 P.M.	9 P.M.
February 25, 1907 -	29.63	29.61	29.47
February 27, 1907 -	29.50	29.47	29.42
February 28, 1907 -	29.35	29.33	29.39

METHODS OF FIRING.

The firing was done by means of "spreading".

Test No. -	1	2	3
Average thickness of fire (inches)	4.5	4.7	5.2
Average intervals between firing 500 lb.(min)	20	20	20
Average intervals between cleaning fires (")	15	15	15

ANALYSIS OF DRY GASES.

Test No. - -	1	2	3
Carbon Dioxide (CO_2) (per cent)	9.0	9.56	8.45
Oxygen (O_2), (per cent)	9.8	8.73	9.95
Carbon Monoxide (CO), (per cent)	.4	.80	.85
Nitrogen (by difference), (N),(per cent)	80.8	80.91	80.75

These analyses were taken in order that a heat balance might be determined for comparison with other tests.

LEAKAGE.

During test No. 2 a leak started about a stay bolt on the right fire sheet. This leakage was caught for five minutes at time of commencing and near close of test. Both weighings showed leakage to be 43 pounds in five minutes and

the duration of the leakage was 1 3/4 hours. The total leakage was taken as 903 pounds.

In test No. 3 the leakage was greater and increased in volume as the test progressed. The following data were taken by weighing leakage at various times. Leakage started at 3:27 P. M.

Time of taking leakage	Minutes Taken	Weight of leakage (lbs)	Leakage per minute (lbs)
4:00 to 4:05	5	7.5	1.50
8.07 " 8:11 1/2	4 1/2	39.5	8.78
10:14 " 10:16 1/2	2 1/2	32.1	12.82

Leakage from 3:27 to 4:00 = 1.5 X 33 = 49.50

Leakage from 4:00 to 8:07 = 247 X 5.14=1,269.58

Leakage from 8:07 to 10:14 = 10.8 X 127=1,371.60

Leakage from 10:14 to close of test 256.4

Total Leakage (lbs) 2,947.08

The above was determined as minutes of time between weighing leakage multiplied by average leakage during that interval.

PARTIALLY BURNED COAL AND ASH.

The chemical analysis of the coal and ash left on grate at end of test and of the ash as taken from pans were as follows:

Partially burned coal and ash used to deaden fire.

Test No. -	1	2	3
Moisture -	.89	.70	.65
Ash -	69.18	70.75	75.93
Total Carbon	25.06	23.53	21.03

Partially burned coal and ash used to deaden fire. (Cont)

Test No. -	1	2	3
Sulphur -	3.64	4.37	2.27
B. T. U. -	4,565	4,311	3,826

Ash.

Test No. -	1	2	3
Moisture -	1.53	1.16	1.13
Ash -	57.17	61.16	70.92
Total Carbon	34.36	31.74	24.97
Sulphur -	3.01	4.16	2.15
B. T. U. -	6,171	5,615	4,600

It will be noticed the carbon and B. T. U. in ash exceeds that in the partially burned coal. This is due to fine coal falling through grates into ash pit, etc. All analyses were made by the department of Chemistry of the University of Illinois.

Owing to an error by analysist the entire moisture was not determined in case of partially burned coal and ash. Owing to leakage this was considerable and for this reason the moisture determinations, made by drying samples, ~~was~~ were taken as correct and amount ashes and partially burned coal was corrected to an amount equivalent to ash as analysed. This was done by finding amount of dry ash and fire using moisture obtained by drying and then referring to equivalent amount as analysed using moisture given by analysist.

MOISTURE DETERMINATIONS.

Test No. 2.	Wt. of sample before drying (lbs)	Wt. of sample after drying (lbs)	moisture %
Partially burned coal -	7.875	6.562	16.68
Ash -	6.187	6.000	3.15
Test No. 3.-			
Partially burned coal -	8.25	7.56	9.57
Ash -	8.000	6.187	22.7

DATA CONCERNING FIRE AND ASH.

Test No. -	1	2	3
Total Ash (dry) (lbs). -	1392	403	
Total Ash (Wet) (lbs). -		790	1148
Partially burned coal and ash used to deaden fire at end of test. (lbs) -	1206	1215	915
Ash used to deaden fire (lbs) -	203	305	218

SAMPLE CALCULATION.

Showing method of deriving item No. 10 calculated data.

Test No. 3.

9,560 (lbs. coal fired) X 10,793 (B. T. U. per lb.) = 103,200,000 B. T. U. fired into grate.

218 (lbs. ash used to deaden fire) X $\frac{.7730}{.9887}$ = 170.5 lbs. = equivalent amount of ash as analysed.

170.5 X 4600 (B. T. U. in ash as analysed) = 784,500= B. T. U. in ash used to deaden fire.

915 lbs. (Partially burned coal and ash) X $\frac{.9043}{.9935}$ =

833 = equivalent amount as analysed.

833 X 3826 (B. T. U. in mixture as analysed) =

3,185,000 B. T. U. in fire and ash.

1148 (lbs ash) X $\frac{.7730}{.9887}$ = 899 lbs.=(equivalent ash as analysed).

899 X 4600 = 4,135,000 B. T. U. lost in ash.

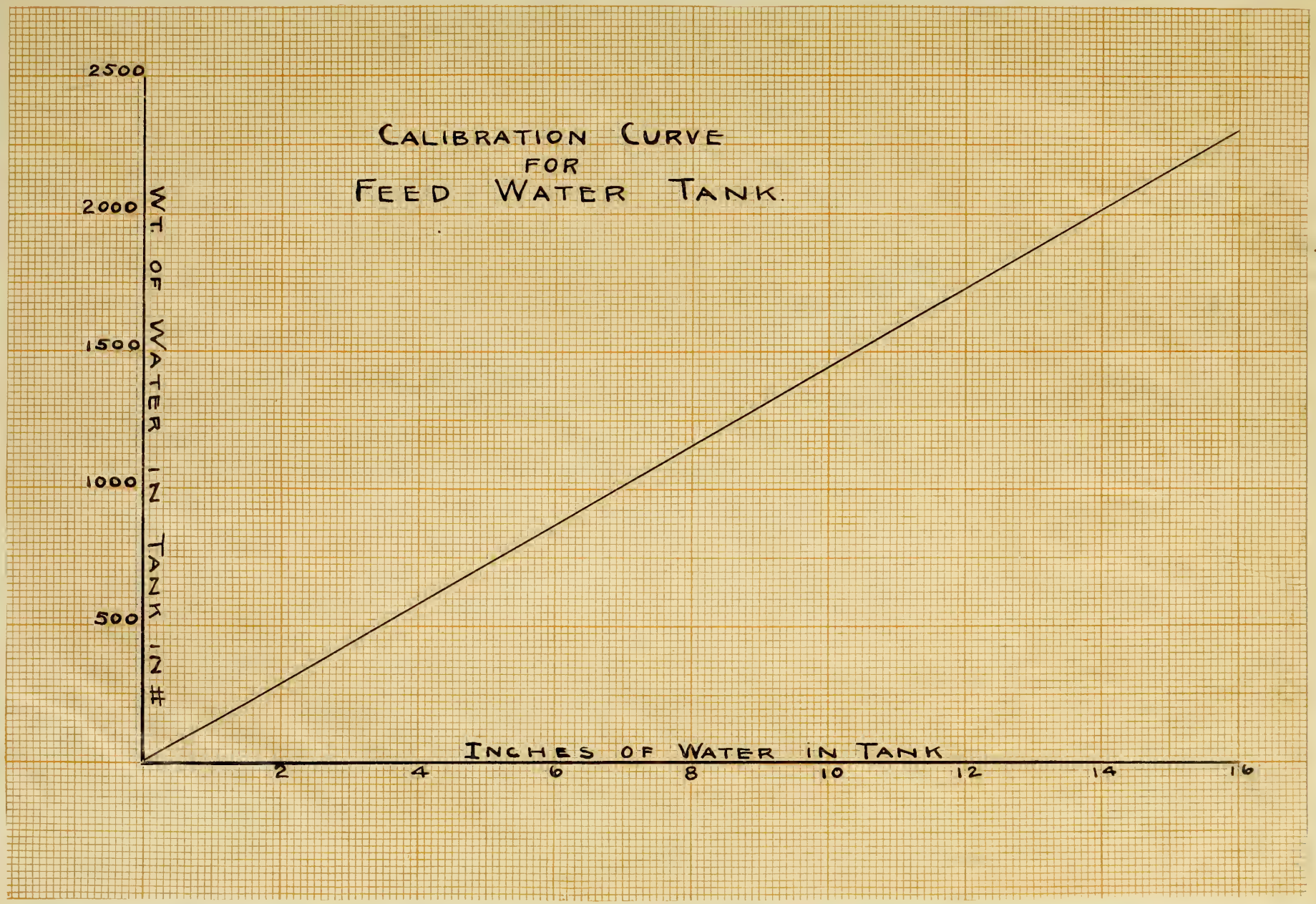
3,185,000 - 784,500 = 1,400,500 B. T. U. in fire on grate actual when B. T. U. thrown on in ash was subtracted.

4,135,000 + 1,400,500 = 5,535,500 B. T. U. lost in partially burned coal and ash.

103,200,000 - 5,535,500 = 97,664,500 B. T. U. actually absorbed by boiler.

97,664,500 ÷ 14,510 = 6730 net lbs. combustible actually absorbed.

$\frac{67080}{6730}$ = 9.97 lbs. = equivalent evaporization from end at 212 degrees per lb. net combustible actually absorbed.


CALIBRATION CURVE
FOR
FEED WATER TANK.
2500
2000
1500
1000
500
WT. OF WATER IN TANK IN #
INCHES OF WATER IN TANK
2
4
6
8
10
12
14
16

At the time set for handing in this thesis the writers were unable to obtain the engine for the second series of tests. This series is to be made and the results thereof embodied in this thesis as supplementary matter.

PART II

All preceding matter (and also part III) was written before tests 4, 5, 6, series 2 were made. The tests of series 2, referred to in this part II, and the calculations, were made under the direct supervision of Mr. E. I. Wenger, with the assistance of Messrs. Ball and Moore, who also assisted in some of the calculations for series 2. Wherever series 2 is referred to in the foregoing, such references have been revised and amended where necessary.

Part II deals with series 2, tests 4, 5, 6 which were made upon engine 6541, after being thoroughly cleaned and overhauled in the Urbana shops.

CONDITION OF ENGINE

The engine was received for test in series 2 before being completely ready for the road. The condition of the boiler was, however, the same as during series 1 except as follows:

All scale which could possibly be removed had been taken out.

The firebox had received new 3/4 side sheets, new 3/4 door sheet, and a new flue sheet; and the boiler had received 91 new radial stays and had been re-tubed.

The boiler was completely lagged but had not yet received the outside iron jacket.

The ash-pans were not hung during tests 4 and 5 but were on during test 6.

The height and diameter of exhaust nozzle, the position

of the netting, and other front end arrangements were measured before series 2 and were found to be the same as previously noted during series 1.

Before test 4 was made the boiler had been twice brought up to pressure and was under fire, in all, 6-1/2 hours before test 4 was started. The condition of the tubes as regards deposit of soot is therefore assumed to be approximately the same as during series 1.

COAL AND FIREMEN

During series 2 the remainder of the same carload of coal was used as had been used for series 1; the coal in the meantime having been protected from the weather by storage within the roundhouse. Fireman Lucot, who fired during all three tests of series 1, also fired during tests 4 and 5 of series 2. During test 6 he was replaced by fireman Warren.

— — — —

MANNER OF CONDUCTING TESTS

The manner of conducting tests as explained for series 1 on pages 2, 3, 4 and 12, 13, 14, 15, 16 applies in all particulars to series 2 except as indicated in the following:-

ENGINE DATA

Same in all respects as for series 1 (pages 2-3).

DATA OBSERVED DURING TESTS

Same as for series 1 (pages 3-4-12), except that there was no boiler leakage (item 23).

METHODS OF OBTAINING DATA

Everything on pages 12 and 13 applies to series 2 except the first paragraph under item 23.

ARRANGEMENT AND DESCRIPTION OF APPARATUS

Except as here noted everything on pages 13, 14, 15, 16 applies to series 2.

Coal was wheeled from storage bin and passed to the platform at the rear of the engine apron.

All instruments used in series 2 were the same ones as had been used for like purposes in series 1.

LOG SHEETS

Checked copies of the original log sheets for tests 4, 5, 6; series 2 are given in the blue print tables immediately following.

1	12:51	621	30	1:17	611	58	7:47	611
2	12:57	622	31	1:20	612	59	7:53	612
3	13:03	623	32	1:23	613	60	7:59	613
4	13:09	624	33	1:26	614	61	8:05	614
5	13:15	625	34	1:29	615	62	8:11	615
6	13:21	626	35	1:32	616	63	8:17	616
7	13:27	627	36	1:35	617	64	8:23	617
8	13:33	628	37	1:38	618	65	8:29	618
9	13:39	629	38	1:41	619	66	8:35	619
10	13:45	630	39	1:44	620	67	8:41	620
11	13:51	631	40	1:47	621	68	8:47	621
12	13:57	632	41	1:50	622	69	8:53	622
13	14:03	633	42	1:53	623	70	8:59	623
14	14:09	634	43	1:56	624	71	9:05	624
15	14:15	635	44	1:59	625	72	9:11	625
16	14:21	636	45	2:02	626	73	9:17	626
17	14:27	637	46	2:05	627	74	9:23	627
18	14:33	638	47	2:08	628	75	9:29	628
19	14:39	639	48	2:11	629	76	9:35	629
20	14:45	640	49	2:14	630	77	9:41	630
21	14:51	641	50	2:17	631	78	9:47	631
22	14:57	642	51	2:20	632	79	9:53	632
23	15:03	643	52	2:23	633	80	9:59	633
24	15:09	644	53	2:26	634	81	10:05	634
25	15:15	645	54	2:29	635	82	10:11	635
26	15:21	646	55	2:32	636	83	10:17	636
27	15:27	647	56	2:35	637	84	10:23	637
28	15:33	648	57	2:38	638	85	10:29	638
29	15:39	649	58	2:41	639	86	10:35	639
30	15:45	650	59	2:44	640	87	10:41	640

Stage-Height Notes
for
Boone River No. 4

Sec. 2 T. 89 N. R. 25 W. of 5 P.M.
Hancock County, Iowa

Observer for October-December 1917
D. Mains

Date and Hour	Stage Above Zero of Gage	Discharge in Second Feet
88	5.70	417
89	6.03	617
90	6.34	825
91	6.44	891
92	6.41	870
93	6.37	839
94	6.25	827
95	6.31	827
96	6.36	861
97	6.47	934
98	6.48	943
99	6.50	956
100	6.53	977
101	7.00	1068
Trans.		11127

FEED WATER SHEET
FOR
BOILER TRIAL No. 3

By J.D Ball. Presented to Commissioners Trials Board 1911
S.B Moore

No of Read.	Time of Read.	Wt of Water Lbs	No of Read.	Time of Read.	Wt of Water Lbs	No of Read.	Time of Read.	Wt of Water Lbs
1	9:15	618	30	10:11	610	59	12:57	618
2	9:30	610	31	10:23	628	60	1:02	622
3	9:35	613	32	10:38	602	61	1:18	620
4	9:40	612	33	10:43	618	62	1:34	622
5	9:46	618	34	10:47	620	63	1:51	618
6	9:49	614	35	10:54	610	64	1:46	622
7	9:54	618	36	10:55	622	65	1:50	618
8	9:57	623	37	10:57	618	66	1:53	622
9	9:04	610	38	11:00	622	67	1:20	612
10	9:08	620	39	11:01	610	68	1:29	624
11	9:12	616	40	11:10	620	69	1:32	613
12	9:14	621	41	11:17	618	70	1:36	622
13	9:20	624	42	11:23	622	71	1:39	620
14	9:25	614	43	11:33	610	72	1:50	620
15	9:29	618	44	11:36	622	73	1:50	623
16	9:31	622	45	11:40	618	74	1:51	622
17	9:35	618	46	11:43	622	75	2:02	618
18	9:40	621	47	11:48	618	76	2:06	622
19	9:45	614	48	11:49	622	77	2:07	613
20	9:49	622	49	11:50	618	78	2:09	622
21	9:52	618	50	11:53	622	79	2:14	623
22	9:55	614	51	11:56	618	80	2:16	622
23	9:57	618	52	12:00	622	81	2:22	623
24	10:05	622	53	12:04	618	82	2:24	622
25	10:07	618	54	12:07	622	83	2:26	617
26	10:11	622	55	12:09	618	84	2:31	622
27	10:13	618	56	12:11	622	85	2:32	613
28	10:16	612	57	12:13	620	86	2:35	622
29	10:23	618	58	12:15	622	87	2:41	613

Field Notes Book

for

Power Test No 5

Dr. [illegible]

[illegible]

Pennsylvania Railroad

Testing Dept. 1907

85	2.02	1825						
87	2.01	1817						
90	2.00	1820						
88	2.03	1827						
84	2.02	1824						
93	2.04	1833						
Total		11746						

FEED WATER SHEET
FOR
BOILER TRIAL No 6

BY J.G. BALL
S.B. HOUSE

PRESENTED FOR UNDERGRADUATE THESIS JUNE 1 1907

No of Read'g	Time & Wt of Pilot Water		No of Read'g	Time of Read'g	Wt of Water	No of Read'g	Time of Read'g	Wt of Water
1	9:05	613.0	32	10:40	613.0	63	1:17	613.0
2	9:13	613.0	33	10:47	628.5	64	1:55	628.5
3	9:15	628.5	34	10:50	613.0	65	1:59	628.5
4	9:21	613.0	35	10:55	628.5	66	2:07	613.0
5	9:26	628.5	36	11:01	613.0	67	2:09	628.5
6	9:29	613.0	37	11:04	628.5	68	2:13	613.0
7	9:33	628.5	38	11:08	613.0	69	2:17	628.5
8	9:36	613.0	39	11:12	628.5	70	2:20	613.0
9	9:39	628.5	40	11:17	613.0	71	2:23	628.5
10	9:46	613.0	41	11:23	628.5	72	2:31	613.0
11	9:51	628.5	42	11:28	613.0	73	2:41	628.5
12	9:56	613.0	43	11:30	628.5	74	2:46	613.0
13	9:57	628.5	44	11:33	613.0	75	2:48	628.5
14	9:58	613.0	45	11:40	628.5	76	2:49	613.0
15	9:59	628.5	46	11:43	613.0	77	2:52	628.5
16	9:59	613.0	47	11:52	628.5	78	2:59	613.0
17	9:22	628.5	48	11:57	613.0	79	3:03	628.5
18	9:24	613.0	49	12:00	628.5	80	3:07	613.0
19	9:27	628.5	50	12:01	613.0	81	3:07	628.5
20	9:29	613.0	51	12:03	628.5	82	3:11	613.0
21	10:01	628.5	52	12:11	613.0	83	3:21	628.5
22	10:09	613.0	53	12:15	628.5	84	3:25	613.0
23	10:12	628.5	54	12:16	613.0	85	3:28	628.5
24	10:14	613.0	55	12:21	628.5	86	3:31	613.0
25	10:16	628.5	56	12:29	613.0	87	3:39	628.5
26	10:19	613.0	57	12:36	628.5	88	3:39	613.0
27	10:22	628.5	58	12:39	613.0	89	3:48	628.5
28	10:27	613.0	59	12:46	628.5	90	3:49	613.0
29	10:35	628.5	60	12:52	613.0	91	3:51	628.5
30	10:38	613.0	61	12:56	628.5	92	3:52	613.0
31	10:40	628.5	62	12:58	613.0	Total		26088

LOG SHEET

27	4:30		57	69	73	530	130		2.5		1.2	285	0
28	4:45	500	57	68	72	530	155	1900	3.1		1.3	282	0
29	4:20		58	68	72	527	155		5		1.2	282	0
30	4:40		60	66	74	520	160		3.1		.9	282	0
31	4:41	500	60	66	74	510	160	21.00	2.8		3	282	0
32	4:55	500	59	65	72	535	180	20.30	3.7		2.5	281	.1
33	5:00		59	65	72	535	170		3.1		1.7	283	0
34	5:18	500	57	65	73	540	180	2100	3.8		1.3	283	0
35	5:20		57	65	73	540	171		3.4		1.3	283	0
36	5:40		57	64	72	530	160		3.5		1.3	285	0
37	5:42	500	57	64	72	530	176	1930	3.0		1.3	281	0

[illegible]

... J. A. [illegible]ale ... [illegible] for [illegible]
... J. Coo[illegible]e ... June [illegible], 1917

No. of Reading	Time of Reading	Wt. of Coal Fired	Temperatures F°: Feed Water	Ex. Air	Inc. Air	Flue Gas	[illegible] Less [illegible]	[illegible] in Inches	[illegible]	Draft: In [illegible]	Draft: [illegible]	[illegible]	[illegible]
1	11:51		5[illegible]	[illegible]	6[illegible]	4[illegible]0°	1[illegible]5	[illegible]	[illegible]		[illegible]		
2	12:0[illegible]		[illegible]	59	6[illegible]	[illegible]90	1[illegible]5	[illegible]00	[illegible]		[illegible]		
[illegible]	12:11	[illegible]	[illegible]	[illegible]9	68	4[illegible]	[illegible]	[illegible]	3.7		[illegible]		
4	12:20		[illegible]	60	68	[illegible]	1[illegible]		[illegible]		[illegible]	[illegible]8	[illegible]
[illegible]	12[illegible]	500	57	60	6[illegible]	52[illegible]	[illegible]65	[illegible]	[illegible]5		1[illegible]	[illegible]	[illegible]
6	12:40		[illegible]	60	[illegible]0	590	1[illegible]	[illegible]	[illegible]		1[illegible]	[illegible]	[illegible]
[illegible]	12:53	50[illegible]	56	[illegible]2	70	59[illegible]	165	1800	[illegible]		1.1	[illegible]3	[illegible]
8	1 0[illegible]		56	[illegible]2	72	[illegible]70	165		[illegible]6		1.[illegible]	2[illegible]	[illegible]
9	1:1[illegible]	500	57	64	70	[illegible]	160		[illegible]8		1	[illegible]	[illegible]
10	[illegible]		5[illegible]	63	[illegible]	[illegible]	16[illegible]		[illegible]0		[illegible]	[illegible]	[illegible]
11	1:27	500	[illegible]	63	7[illegible]	[illegible]	[illegible]8[illegible]	[illegible]	[illegible]		[illegible]	[illegible]	[illegible]
12	1 [illegible]		5[illegible]	63	70	56[illegible]	1[illegible]		90		[illegible]	[illegible]3[illegible]	[illegible]
13	1:4[illegible]	500	[illegible]	[illegible]3	7[illegible]	5[illegible]	[illegible]	[illegible]	78		14	[illegible]	[illegible]
14	2:00		[illegible]7	[illegible]	7[illegible]	[illegible]	[illegible]		[illegible]		[illegible]	28[illegible]	[illegible]
[illegible]5	2:[illegible]	[illegible]	57	[illegible]	72	[illegible]40	1[illegible]0	21[illegible]	4.8		[illegible]	[illegible]	[illegible]
16	2 20		5[illegible]	[illegible]5	72	[illegible]	1[illegible]		2[illegible]		1[illegible]	28[illegible]	[illegible]
17	[illegible]21	50[illegible]	[illegible]7	65	72	58[illegible]	170	1[illegible]0	[illegible]		1.[illegible]	2[illegible]	[illegible]
18	2 [illegible]		57	66	7[illegible]	[illegible]45	17[illegible]		[illegible]		1[illegible]	282	[illegible]
1[illegible]	2:32	500	57	66	72	54[illegible]	17[illegible]	1700	[illegible]		[illegible]	[illegible]	[illegible]
[illegible]0	2:59	500	57	68	72	53[illegible]	16[illegible]	[illegible]0	4.0		[illegible]	28[illegible]	[illegible]
21	3:00		57	[illegible]8	7[illegible]	[illegible]	165		4.0		[illegible]	[illegible]	[illegible]
22	3:16	500	57	68	[illegible]	[illegible]20	17[illegible]	17[illegible]	3.3		[illegible]	[illegible]8[illegible]	[illegible]
23	3 2[illegible]		5[illegible]	68	7[illegible]	[illegible]	[illegible]		3.3		1[illegible]	[illegible]	[illegible]
24	3 35	500	[illegible]	68	72	520	1[illegible]0	2[illegible]	[illegible]0		1[illegible]	[illegible]	[illegible]
[illegible]5	[illegible]4[illegible]		[illegible]7	[illegible]	[illegible]	585	1[illegible]0		[illegible]9		14	[illegible]80	[illegible]
2[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	5[illegible]0	1[illegible]	[illegible]20	2[illegible]		[illegible]	28[illegible]	[illegible]
2[illegible]	[illegible]00		57	69	7[illegible]	530	1[illegible]		2.3		[illegible]	28[illegible]	[illegible]
28	4 15	500	57	62	72	530	155	1900	11		[illegible]3	282	[illegible]
29	4 20		58	[illegible]8	72	527	1[illegible]5		[illegible]5		1[illegible]	282	[illegible]
30	4 [illegible]		60	[illegible]	74	520	[illegible]60		[illegible]1		.9	28[illegible]	[illegible]
31	4.41	[illegible]00	[illegible]0	[illegible]6	74	510	[illegible]60	21[illegible]	[illegible]8		[illegible]	[illegible]	[illegible]
32	[illegible]55	[illegible]00	59	65	72	535	[illegible]0	[illegible]030	[illegible]7		[illegible]	[illegible]	.1
3[illegible]	5:00		[illegible]9	6[illegible]	72	535	1[illegible]0		[illegible]		1[illegible]	[illegible]	[illegible]
34	5.15	[illegible]	[illegible]	[illegible]5	73	5[illegible]	180	[illegible]	38		1[illegible]	[illegible]	[illegible]
35	5.[illegible]		[illegible]	6[illegible]	73	[illegible]40	171		[illegible]4		[illegible]3	28[illegible]	[illegible]
36	[illegible]		[illegible]	[illegible]	[illegible]2	[illegible]	160		[illegible]		[illegible]3	[illegible]8[illegible]	[illegible]
3[illegible]	[illegible] 42	[illegible]	5[illegible]	[illegible]	72	[illegible]0	[illegible]	[illegible]	[illegible]		13	28[illegible]	[illegible]
38	6 [illegible]		[illegible]	63	72	[illegible]	1[illegible]0		[illegible]		[illegible]	[illegible]	0
39	6 [illegible]	[illegible]	[illegible]	62	[illegible]	[illegible]00	[illegible]65	[illegible]	[illegible].6		1[illegible]	[illegible]	[illegible]
[illegible]0	6 [illegible]		5[illegible]	[illegible]	[illegible]	[illegible]20	172		[illegible]		10	28[illegible]	[illegible]
41	6 35	[illegible]	[illegible]	60	72	[illegible]5	[illegible]5	[illegible]	[illegible]0		[illegible]	[illegible]	[illegible]
[illegible]	6 [illegible]		[illegible]	[illegible]	[illegible]	53[illegible]	15[illegible]		[illegible]		[illegible]	[illegible]	[illegible]
[illegible]	6 [illegible]	[illegible]	[illegible]	[illegible]0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		[illegible]	[illegible]	[illegible]
4[illegible]	[illegible]		[illegible]	60	[illegible]	[illegible]5	[illegible]	[illegible]	[illegible]		[illegible]	[illegible]	[illegible]
Total		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]				[illegible]	[illegible]	[illegible]
Av.			57.[illegible]	[illegible]8	[illegible]	[illegible]30	[illegible]				[illegible]	[illegible]	[illegible]

27	1:00		60	71	70	475	175		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
28	1:05	500	60	71	70	485	160	17.0	5.4	.02	.6	286	0
29	1:18	500	60	71	70	520	172	16.0	4.0	.02	1.4	281	0
30	1:20		60	71	70	520	190		4.3	.02	1.4	282	0
31	1:40		60	71	70	550	172		3.5	.02	1.3	284	0
32	1:53	500		71	70	550	168	16.5	2.9	.02	1.3	284	0
				[illegible]	[illegible]	550	165		2.3	.02	1.2	284.5	0

Boiler Trial No 5

By J. J. Bault

Tuesday June 19 1917

No	Time	W. of Air	W. of Feed	Temperature F° Feed	Int.	Gas	Steam Pressure in Boiler	Vacuum in Uptake	Ht. of Water in Gauge Glass Inches	Draft In Ft.	Draft In Inches	Calorimeter Temp.	Calorimeter Moisture
1	8:15		58°				158	145	27	.13			
2	8 30						158		27				
3	8 25	5	57				176	19.0	27	03			0.1
4	8 40		59	60°	68°		170		6.6	02	13	284°	0.2
5	8 52			60°	68		160	160	50	.02	13	286	0.1
6	3 00			60°	64	550°	165	1625	42	02	10	286	01
7	9.13	500		60	64	550	170	9.5	51	.02	10	289	01
8	9 20		59	60	64	550	168		42	.02	11	288	01
9	9 30			60	64	565	176	10.25	1.3	02			
10	9 40		58	64	64	565	170		47	.02	11	288	01
11	9 53	500		64	66	565	166	7.5	47	02	11	288	01
12	10 00		58	64	66	565	160		3.5	.02	11	288 5	01
13	10 05	20		65	67	573	172		30	.02	1.3	288.3	0.1
14	10 20			66	68	5 15	163	8.0	30	02	1.3	288	0.0
15	10 26		59	66	63	568	165		30	02	1.5	287.5	0.05
16	10 40	500	59	66	68	530	160	12.0	13	.02	1.3	285 5	0:04
17	11 .0	500	58	65	68	535	170	7.0	40	.02	1.2	281	0 15
18	11 20		60	6	67	550	165		8.0	02	16	275	1
19	11 30	500		64	67	540	158	19.0	20	02	1.3	288	01
20	11 40		59	63	67	545	165		25	.02	13	286	0
21	11 51	500		68	0	545	160	17	25	.02	15	280	0
22	12.00		62	68	71	545	170		30	.02	15	288	0
23	12 -1	500		69	69	560	162	15.0	43	.01	11	286	0
24	12 20			69	69	560	170		7.3	.01	1	2 2	0
25	12 3			70	69	560	169		8.5	.02	11	278	
26	12 40		59	69	69	555	182		100	2	1.1	27	
27	1 00		60	72	70	595	170		70	2	1	284	
28	1 05	500	60	71	70	48	160	170	5.4	.02	.6	286	0
29	1 10	500	60		70	520	172	16.0	40	.02	14	281	0
30	1 20		60	71	70	520	18		53	02	14	282	0
31	1 40		60	71	70	550	172		3.5	.02	13	284	0
32	1 45	500		71		550	150	16.5	2	02	1 1	284	0
33	2 00		62	71	70	550	163		23	02	12	284 5	0
34	0	500		71	70	557	160	140	28	.0	12	284	0
35	2		60	71	70	550	155		12	02	2	28	0
36	2 2	00		71	70	550	170	6	15	.02	2	286	0.0
37	2	00	60	70	69	560	156	170	27	.02	16	283	0
38	2	500		70	69	560	167		27	.02	16	283	0
39	2	0		70	69	55	162	20.0	70	02	14	283	0
40				70	70	570	173		32	02	2	285	0
41	2			70	69	580	175	5	2		2	284	
			3	549	2590	19771	681			.3		1	
			6	7.0	0816	4	510			1		287 5	0

26	12:20		61.0	72	75	555	176		5.25	.090	1.3	285	0
27	12:27	500		72	75	550	162	15:25	5.8	.080	1.3	283	0
28	12:40		60.0	72	74	565	165		5.8	.070	1.5	282	0
29	12:47	500		72	74	550	170	17.50	5.3	.085	1.4	284	0
30	1:00		60.0	72	74	560	173		6.2	.070	1.5	282	0

LOG SHEET

FOR

BOILER TRIAL No 6

BY J.U. BALL PRESENTED [illegible] JUNE 1 1907
S.B. MOORE.

No. of Reading.	Time of Reading	Weight of Coal Fired	Temperatures-F				Steam	Ht of Water in Tank	Ht of Water in Gage Glass	Draft		Calorimeter	
			Feed Water	Ext Air	Int Air	Flue Gas	Pressure	Inches	Inches	In Pit Inches	Front End Inches	Steam Temp	Manometer Inches
1	8.00	150# Wood	59.0	65	68	490	175	17.25	6.0	[illegible]	.3		
2	8.16	500		68	67	500	175	17.00	5.2	.010	.5	283	2
3	8:20		60.0	68	68	500	175		7.1	010	.6	283	.05
4	8:29	500		66	68	505	172	16.50	5.0	020	.7	288	.05
5	8.40		60.0	66	67	515	173		5.2	.010	.7	283	05
6	8'49	500		67	69	525	180	17.50	4.0	.020	.6	283	05
7	9:00		60.0	69	69	505	170		3.3	015	.5	283	.0
8	9:15	500		68	70	550	164	19.50	2.0	040	1.1		
9	9:20		59.0	68	70	565	165		5.2	[illegible]	[illegible]	286	[illegible]
10	9:40		59.5	68	70	550	180	17.00	7.7	100	.9	287	05
11	9:42	600		68	70	550	181		7.5	090	.9	280	.05
12	10.00		59.0	70	71	520	160	17.25	2.3	045	1.1	280	05
13	10:02	500		70	71	520	160		2.3	04[illegible]	1.1	2[illegible]	05
14	10:14	500		71	72	590	180	14.75	4.2	.060	1.6	280	0[illegible]
15	10:20		59.0	71	72	600	184		5.7	.080	1.6	280	04
16	10:38	500		71	72	570	177	16.25	6.5	.080	1.6	281	.04
17	10:40		59.0	71	72	575	185		6.3	.050	1.6	281	0[illegible]
18	11:00		59.0	71	72	550	180	16.25	5.2	.060	1.8	282	.04
19	11:04	500		71	72	550	173		5.8	.060	1.6	28[illegible]	.04
20	11:25		59.5	71	72	550	190	17.00	4.2	.040	2.0	282	.04
21	11:28	500		71	72	550	192		4.0	.040	2.0	282	.04
22	11:40		60.0	71	73	550	180		5.4	.070	1.6	283	.04
23	11:47	500		71	74	550	171	17.50	5.3	.070	1.6	283	.04
24	12.00		61.0	71	74	555	18[illegible]		5.0	085	1.6	283	[illegible]
25	12:06			71	74	56[illegible]	172	2.50	5.5	.070	1.6	286	0
26	12:20		61.0	72	75	555	176		5.25	040	1.3	285	0
27	12:27	500		72	75	550	162	15.25	5.8	.080	1.3	28[illegible]	0
28	12:40		60.0	72	74	565	165		5.8	.070	1.5	282	0
29	12:47	500		72	74	550	170	17.50	5.4	085	1.4	284	0
30	1:00		60.0	72	74	560	173		6.[illegible]	.070	1.[illegible]	282	0
31	1:08	500		72	74	550	187	18.50	4.3	085	1.[illegible]	283	0
32	1:20		60.0	72	74	585	187	18.00	5.5	060	1.[illegible]	284	0
33	1:24	500		74	76	585	183		6.5	[illegible]	1.[illegible]	283	0
34	1:40		61.0	74	76	565	175	15.00	4.3	040	1.3	28[illegible]	
35	1:44	500		74	76	545	170		4.5	070	1.5	284	0
36	2:00		60.0	73	74	565	170	19.25	4.3	070	1.4	28[illegible]	
37	2.02	500		73	74	565	180		4.[illegible]	070	1.4	284	0
38	2:20	500	60.0	73	74	565	175	18.75	4.7	.070	1.2	282	0
39	2:22			73	74	560	175		4.2	.070	1.2	285	0
40	2:35	500		73	74	555	180	18.50	5.0	080	1.4	285	0
41	2:40		60.0	73	74	590	180		5.5	060	1.[illegible]	28[illegible]	0
42	2:50	500		73	74	605	185	19.25	6.0	07[illegible]	1.[illegible]	28[illegible]	[illegible]
43	2:55		60.0	73	74	525	155	16.25	[illegible]	.040	0.0		
Total		10000	1316	3043	3104	3[illegible]	7[illegible]				5[illegible]	1[illegible]85	
Aver.			59.8	0.7	72	5[illegible]	179			0[illegible]	1.2	2[illegible]	

CALCULATED DATA AND RESULTS

RESULTS OF TESTS NOS. 4, 5, 6.

2. Time and Duration				
2.1 Number of test		4	5	6
2.2 Date of test		5/28/07	5/29/07	5/30/07
2.3 Duration of test	hours	7.14	6.77	6.92
3. Average Pressures				
3.1 Of steam in boiler, gauge pressure	lbs. per sq. in.	167.1	170.4	171.4
3.2 Of atmosphere	in.of mercury	29.26	29.15	29.06
3.3 Of steam in calorimeter, by manometer	in.of mercury	0.06	0.04	0.03
3.4 Of draught in front end,	inches of water	1.11	1.04	1.26
3.5 Of draught in ash-pan	inches of water	0.02	0.02	0.06
4. Average Temperatures	deg. Fahr.			
4.1 Of external air		64.1	63.7	70.8
4.2 Of roundhouse		71.3	68.2	72.3
4.3 Of steam in boiler		373.5	375.1	375.7
4.4 Of steam in calorimeter		283.05	284.5	282.0
4.5 Of feed water entering injector		57.5	59.4	60.2
4.6 Of escaping gases		536.	543.	552.
5. Fuel				
5.1 Moist coal consumed	lbs.	10500.	10000.	10500.
5.2 Wood consumed	lbs.	66.	141.	150.

			4	5	6
5.3 Coal equivalent of wood, (Item 5.2 x 0.4)	lbs.		27.	56.	60.
5.4 Total coal consumed, including wood equivalent	lbs.		10527.	10056.	10560.
5.5 Moisture in coal		%	10.57	11.09	8.36
5.6 Dry coal consumed	lbs.		9420.	8891.	9680.
5.7 Total ash and refuse	lbs.		1885.	1582.	1303.
5.8 Total combustible	lbs.		7850	7655.	8050.
Fuel per Hour					
5.9 Dry coal consumed per hour	lbs.		1343.	1313.	1398.
5.10 Combustible consumed per hour	lbs.		1100.	1131.	1163.
5.11 Dry coal per square foot of grate surface per hour	lbs.		39.2	38.3	40.8
5.12 Combustible per square foot of water heating surface per hour	lbs.		0.389	0.401	0.412
Proximate Analysis of Coal					
5.13 Fixed carbon		%	36.53	37.88	38.46
5.14 Volatile matter		%	37.98	38.20	37.78
5.15 Moisture		%	10.57	11.09	8.36
5.16 Ash		%	14.92	12.83	15.40
5.17 Combustible (item 5.13 + 5.14)		%	74.51	76.08	76.24
(for ultimate analysis see appendix)					
Calorific Value of Fuel					

		4	5	6
5.18 By oxygen calorimeter per pound of coal	B.T.U.	10320.	10632.	10693.
5.19 By oxygen calorimeter per pound of combustible	B.T.U.	13860.	13970.	14020.
5.20 By analysis, per pound of coal	B.T.U.	10388.	10812.	10758.
5.21 By analysis, per pound of combustible	B.T.U.	13950.	14180.	14110.
6. Water				
6.1 Total water delivered to feed tank	lbs.	62127.	57596.	56833.
6.2 Correction for level in tank	lbs.	0	-750	+150
6.3 Total water fed to boiler	lbs.	62127.	56846.	56.983.
6.6 Equivalent water fed to boiler from and at 212 degrees F.	lbs.	75450.	68850.	69050.
6.7 Moisture in steam	%	0.65	1.77	1.82
6.8 Quality of steam (dry steam = unity)		0.994	0.982	0.982
6.9 Water actually evaporated, corrected for quality of steam	lbs.	61720.	55850.	55970.
6.10 Factor of evaporation		1.2123	1.2105	1.2102
6.11 Equivalent water evaporated into dry steam from and at 212°F.(item6.9x6.10)	lbs.	75000.	67600.	67790.

			4	5	6
6.12	Water evaporated per hour, corrected for quality of steam	lbs.	8650.	8258.	8091.
6.13	Equivalent evaporation per hour from and at 212° F.	lbs	10515.	9960.	9795.
6.14	Equivalent evaporation per hour from and at 212° F. per square foot of water-heating surface	lbs.	3.715	3.525	3.462
7. Horse Power					
7.1	Horse power developed (34-1/2 lbs of water evaporated per hour into dry steam from and at 212° F.= one horse power	H.P.	309.	288.	284.
8. Efficiency					
8.2	Efficiency of the boiler:- heat absorbed by boiler per pound of combustible, divided by heat value of one pound of combustible	%	61.8	55.7	53.2
9. Evaporative Performance					
9.1	Water apparently evaporated under actual conditions of test per lb. of coal as fired. (Item 6.3 ÷ item 5.4)	lbs.	5.92	5.62	5.40
9.2	Equivalent evaporation from and at 212 degs. Fahr. per				

		4	5	6
pound of dry coal (item 6.11 ÷ item 5.6)	lbs.	7.97	7.60	7.05
9.3 Equivalent evaporation from and at 212° F. per pound of coal as fired (item 6.11 ÷ item 5.4)	lbs.	7.13	6.72	6.42
9.4 Equivalent evaporation from and at 212° F. per pound of combustible (item 6.11 ÷ item 5.5)	lbs.	9.55	8.84	8.45
10. Economic Result Desired in These Tests				
10.1 Equivalent evaporation from and at 212° F. per pound of net combustible actually consumed by boiler	lbs.	10.94	10.08	9.293

METHODS OF CALCULATION

Except the matter relating to item 6.4 all methods noted on pages 21 and 22 apply to series 2 as well as to series 1.

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CONCLUSION

The effect of scale is shown by a comparison of the equivalent evaporation from and at 212° F. per pound of combustible consumed, as obtained in series 1; with that obtained in series 2.

For convenience these results (items 10.1) for both

series are assembled in the following table.

Equivalent Evaporation from and at 212 degrees F.
per pound of Combustible Actually Consumed.

SERIES 1 Scale in Boiler				SERIES 2 Scale Removed			
Test No.	1	2	3	Test No.	4	5	6
	9.74	10.14	9.97		10.94	10.08	9.29
Average for Series 1	9.95			Average for Series 2	10.10		
For Test #1	9.74			For Tests #4 & #5	10.51		

The leakage of the boiler attending tests 2 and 3 was due to the boiler condition, and could not be eliminated in spite of repeated attempts to do so; the tests having been started 4 times and discontinued in the effort to make the boiler tight. For leakage determinations see appendix A. The method of its determination assumes uniformity of rate of leakage between intervals, which assumption is unwarranted. On this account it seems proper to disregard both tests 2 and 3 of series 1 in making a comparison.

Consideration of all conditions surrounding series 2 indicates that the only respects in which test 6 is less reliable than nos. 4 and 5 is in the difference in firemen and in the difference in the moisture in coal.

There is no specific reason for suspecting the accuracy of the moisture determination. The fireman in test 6 did

not however handle his fire quite as successfully as did fireman Lucot in the preceding tests. For such reasons, although perhaps inadequate, it seems advisable to disregard also the results of test 6 in making a comparison.

Comparing therefore test 1 of series 1 with tests 4 and 5 of series 2 we have the following loss due to the presence of scale in the boiler.

LOSS DUE TO SCALE = $\frac{10.51 - 9.74}{10.51}$ = 7.26 per cent

APPENDIX B - FOR SERIES #2

OBSERVERS

Series 2 was made under the direct supervision of Mr. E. I. Wenger, assisted by Messrs. J. D. Ball and S. B. Moore. Gas analyses were made by Mr. Moore.

Other observers were:-

W. E. Alley P. S. Freeman L. H. Mueller

Fireman Lucot fired tests 4 and 5 and fireman Warren fired test 6.

BAROMETER READINGS

Compiled from records of the University Station of the U. S. Weather Bureau Climatological Service.

	May 28	May 29	May 30
7:00 A. M.	29.25	29.15	29.07
12:00 M.	29.27	29.16	29.07
6:00 P. M.	29.26	29.15	29.03
Average	29.26	29.15	29.06

METHODS OF FIRING

The fire was "spread". Other conditions were as follows:-

	Test 4	Test 5	Test 6
Average thickness of fire ins.	5.0	5.2	5.0
Average interval between firing min.	4	4	4
Average interval between cleanings min.	27 ~~26~~	33	28 ~~27~~

GAS ANALYSES

6 Analyses of flue gases were made during test 4, 4 during test 5, and 5 during test 6.

The averages of these analyses of the dry gases are as follows:-

		#4	#5	#6
Carbon Di-oxide (CO_2)	%	6.6	5.55	7.72
Oxygen (O)	%	12.3	13.6	10.08
Carbon Monoxide	%	0.3	2.5	0.4
Nitrogen (N) by difference	%	80.8	78.35	81.8

COAL DATA

Mechanical Analysis

During tests 4 and 6, a weighed coal sample was sorted with results as given below. This was not done for test 5.

		#4 300#sample	#6 84#sample
Lump	%	29.3	45.2
Small (2" mesh	%	48.7	25.6
Slack (3/4" mesh)	%	22.0	29.2

Moisture Determination

Samples of coal, weighed before and after drying during tests 4 and 5 (omitted in #6), gave the following results. These determinations were made as a check on the analyses.

		#4	#5
Weight before drying	lbs.	6.5	6.4
Weight after drying	lbs.	5.75	5.75
Moisture	%	11.5	10.15

Chemical Analyses

Chemical analyses of coal gave the following results:-

		#4	#5	#6
Moisture	%	10.57	11.09	8.36
Ash	%	14.92	12.83	15.40
Sulphur	%	4.84	4.14	4.90
Volatile matter	%	37.98	38.20	37.78
Fixed carbon	%	36.53	37.88	38.46
Total carbon	%	57.45	59.82	59.97
Available hydrogen	%	3.01	3.13	3.11
B.T.U. per lb., by calorimeter		10320.	10632.	10693.
B.T.U. per lb., calculated		10388.	10812.	10758.

PARTIALLY BURNED COAL AND ASH DATA

Chemical Analyses

Analyses of Partially Burned Coal remaining on grate at end of tests plus the wet Ash used to deaden fire:-

		#4	#5	#6
Moistur e	%	17.44	13.01	4.02
Ash	%	64.20	57.50	69.75
Sulphur	%	2.62	3.05	2.29
Total carbon	%	17.93	28.07	25.68
B.T.U.per lb., by calorimeter		2797.	4507.	3970.

Analyses of Ash removed from ash pit during test, after being wet down:-

		#4	#5	#6
Moisture	%	23.46	19.40	7.02
Ash	%	36.40	44.75	54.20
Sulphur	%	2.80	2.42	2.49
Total Carbon	%	35.06	32.26	34.77
B.T.U.per lb.,by calorimeter		6065.	5374.	5810.

Moisture Determinations

As a rough checked on the analyses, determinations were made of moisture in the ash in tests 4 and 5 (omitted in 6); and also of the moisture in the partially burned coal plus ash in test 5 (omitted in 4 and 6). The results are as follows:-

For the partially burned coal plus ash -

		#5
Weight before drying	lbs.	6.25
Weight after drying	lbs.	5.50
Moisture	%	12.10

For the ash -		#4	#5
Weight before drying	lbs.	6.88	5.13

		#4	#5
Weight after drying	lbs.	5.88	4.38
Moisture	%	14.57	14.60

Other Data

	#4	#5	#6
Total wet ash removed from ash-pit during test lbs.	1885.	1582.	1303.
Total dry ash (based on analysis) lbs.	1442.	1275.	1211.
Partially burned coal on grate at end of test plus wet ash used to deaden fire lbs.	1035.	1070.	980.
Wet ash used to deaden fire lbs.	217.	237.	252.
Equivalent dry ash used to deaden fire lbs.	166.	191.	235.

P A R T III

As auxiliary to the tests herein described an attempt was made to determine the effect of scale by a comparison of locomotive performance before and after cleaning boiler. The engine previous to testing was used a few weeks in switching service. For the comparison of performances this time was not considered and results were based on coal used per ton mile six months before time of entrance in switching service and six months after cleaning the boiler. The following data WERE compiled from office records.

Before Cleaning.

	1st of the 6 months	2nd of the 6 months	3rd of the 6 months	4th of the 6 months	5th of the 6 months	6th of the 6 months
1. Coal consumption in tons -	226	99	437	246	263	279
2. Mileage -	2342	386	1948	1916	1417	1189
3. Gross tonnage handled	29,773	5,477	37,020	24,920	23,914	14,937
4. Gross ton miles (tonnage x mileage)	1,732,599	181,190	1,327,660	774,093	1,121,179	663,567

After Cleaning.

1. Coal consumption, tons -	238	192	227	232	304	269
2. Mileage -	2,515	1,947	2,514	1,885	2,704	2,033
3. Gross tonnage handled	45,797	33,806	49,124	36597	48,149	37,319
4. Gross ton miles	2,996,952	2,364,991	3,837,058	3,296,570	3,537,641	3,140,730

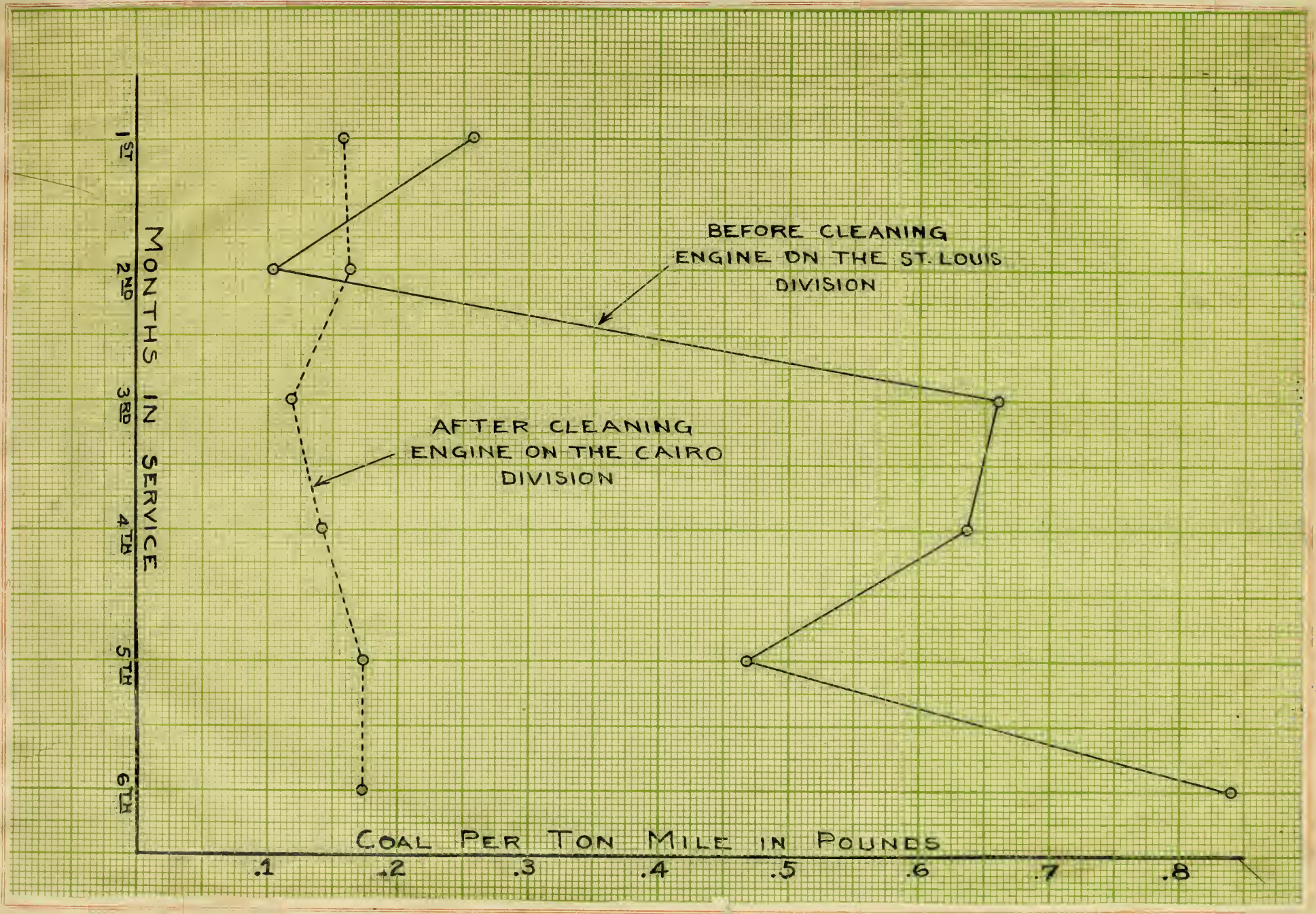
From above data was calculated coal used per ton mile as follows: (See also curve on Page 60).

	1st of the 6 months	2nd of the 6 months	3rd of the 6 months	4th of the 6 months	5th of the 6 months	6th of the 6 months
Before Cleaning	.261	.109	.658	.630	.467	.841
After Cleaning	.159	.162	.118	.141	.172	.171

The coal consumption on division 1st 6 months 140,460 tons.

The coal consumption on division 2nd 6 months tons.

Unfortunately the engine was put on the Cairo division after it was cleaned, while it had been used on the St. Louis division before being cleaned. As the grades are not as heavy on the Cairo division as they are on the St. Louis division, the above comparative results are thereby made almost worthless.


BEFORE CLEANING
ENGINE ON THE ST. LOUIS
DIVISION
AFTER CLEANING
ENGINE ON THE CAIRO
DIVISION
MONTHS IN SERVICE
1ST
2ND
3RD
4TH
5TH
6TH
COAL PER TON MILE IN POUNDS
.1
.2
.3
.4
.5
.6
.7
.8